POTENTIAL FOR WATER YIELD IMPROVEMENT IN ARIZONA THROUGH RIPARIAN VEGETATION MANAGEMENT

by

Richard Steven Affleck

A Dissertation Submitted to the Faculty of the

SCHOOL OF RENEWABLE NATURAL RESOURCES

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY
WITH A MAJOR IN WATERSHED MANAGEMENT

In the Graduate College

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GRADUATE COLLEGE

I hereby recommend that this dissertation prepared under my direction by Richard Steven Affleck

entitled POTENTIAL FOR WATER YIELD IMPROVEMENT IN ARIZONA THROUGH RIPARIAN VEGETATION MANAGEMENT

be accepted as fulfilling the dissertation requirement of the degree of DOCTOR OF PHILOSOPHY

David B. Thorud — January 27, 1975
Dissertation Director — Date

After inspection of the final copy of the dissertation, the following members of the Final Examination Committee concur in its approval and recommend its acceptance:*

David B. Thorud	January 27, 1975
Donald F. Post	February 10, 1975
David W. Hendricks	February 10, 1975
Malcolm J. Zwolinski	Feb. 10, 1975
Peter F. Ffolliott	Feb. 10, 1975

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ABSTRACT

New knowledge gained over the past 15 to 20 years on the management of riparian zones in Arizona for water yield improvement has been organized and analyzed. Hydrologic processes and principles applicable to riparian zones, the distribution and nature of riparian vegetation in Arizona, and new resource management methods, needs, and constraints have been evaluated. The relationship between vegetation management for water yield improvement and other resource-based products and uses of riparian zones such as timber, range for livestock, wildlife and fish, recreation, and aesthetics was also assessed.

Past studies and surveys indicate that Arizona has approximately 280,000 to 320,000 acres of riparian vegetation. However, pertinent information such as species composition, vegetation density, depth to groundwater, groundwater quality, and landownership have not been mapped accurately for many riparian zones in Arizona. A continuous survey of riparian vegetation cover by remote sensing supplemented by ground truth is suggested to remedy this situation.

Analysis of hydrologic studies indicated the following identifiable trends in water use by riparian species. Saltcedar, arrowweed, cottonwood, and hydrophytes

are the heaviest users of water (between four and eight feet of water annually). Intermediate water users (annual use between two and five feet) are seepwillow, mesquite, quailbrush, four-wing saltbush, and greasewood. Lesser amounts of water are transpired by grasses and sedges and evaporated from bare soil (0.5 to three feet annually).

Five water yield improvement methods applicable to riparian zones are evaluated; conversion of one vegetation type to another, channelization, cottonwood thinning, anti-transpirant and biological control treatments.

Conversion treatments to grasses or crops may yield water savings of up to 2.5 acre-feet per acre annually during the first year. However, some or all of this water may eventually be used by replacement vegetation. Several constraints including possible loss of wildlife habitat, contamination of water supplies by chemical herbicides, lowered aesthetic quality, and increased soil erosion with the removal of riparian vegetation reduce the opportunities for converting a large percentage of riparian vegetation in Arizona. To justify operational conversion programs in Arizona follow up studies of current conversion projects should be instituted. Rates at which revegetation takes place, declines in water salvage as revegetation occurs, amount and value of increased herbage production, and long term effects on plant distribution and animal life need to be determined.

Channelization projects in the Southwest have been credited with increasing water yields; however, methods for determining these increases are poorly documented. Channelization for flood control purposes is limited because flow of flood water is accelerated in the vicinity of the excavation and may contribute to flooding and sedimentation on unchanneled segments.

Cottonwood thinning designed to reduce evapotranspiration and flood hazards has been conducted along the Verde River. Increased water yields have not been measured. Adverse effects on fish and wildlife have been reported as a result of thinning cottonwoods. Limited thinning of cottonwoods to prevent bridges from washing out or to protect existing structures on the floodplain may be beneficial.

Application of antitranspirant foliar sprays to reduce plant water use is a potential treatment method for increasing water yield in riparian zones. Antitranspirants were effective in reducing transpiration rates of saltcedar plants by up to 38 per cent for three to five weeks in greenhouse and limited field studies. Research on the feasibility of obtaining supplementary water from riparian vegetation through the application of antitranspirants should be expanded. Antitranspirants, if proven safe and effective, may be mutually acceptable to water, recreation, and wildlife interests.

Biological control of saltcedar is not effective at present.

INTRODUCTION

Streams, rivers, and floodplains have been important sources of water in the arid southwest for agriculture, industry, and municipal uses. These water resources also can have high recreation and aesthetic value and may provide prime habitat for fish and wildlife. Many plant species inhabit riparian sites and the environmental factors that influence their development are diverse.

Riparian plants have high transpiration rates because the water supply is continuous and the environment is warm and arid. In addition, dense stands of riparian vegetation growing in channels and on floodplains form a partial barrier to flood flows, which increases channel roughness and causes the water to spread over adjacent areas that normally might not be flooded. Furthermore, by reducing the velocity of flood flows, the ponding or damming effect that results increases sedimentation within the channel. Such sedimentation, in turn, reduces the capacity of channels to carry flood water, and as a result, further increases flood hazards on adjoining lands. These and other factors have produced an intense and controversial interest in the management of riparian vegetation.

The potential for water yield improvement in Arizona through riparian vegetation management was discussed by Barr

(1956). Since publication of the Barr report, new knowledge has developed concerning hydrologic processes and principles applicable to riparian zones, and on the distribution and nature of riparian vegetation in Arizona. New resource management methods, needs, and constraints have also evolved over the past 15 years. However, the need for increased water supplies in Arizona is still considered significant by many observers.

The objectives of the present study are to organize, analyze, and make available to decision-makers this new knowledge about the management of riparian zones for water yield improvement. The relationship between vegetation management for water yield improvement and other resource-based products and uses of riparian zones such as timber, range, wildlife and fish production, recreation activity, and aesthetic values are also evaluated. Five water yield improvement methods applicable to riparian zones are evaluated. These include conversion of one vegetation type to another, channelization, cottonwood thinning, anti-transpirant and biological control treatments. The latter two methods have not been implemented on an operational scale and are only considered potential methods for increasing water yields in riparian vegetation areas.

Each of the five water yield improvement methods is evaluated as follows:

1. All literature, reports, and summaries applicable to Arizona on matters pertaining to (a) hydrology, (b) extent of riparian vegetation by type and management status, (c) impacts of management of riparian vegetation on the other resource-based products and uses, and (d) economic considerations of the management alternatives applicable to riparian zones are reviewed and summarized.
2. Personal communication with scientists, land managers, and other decision-makers (Appendix A) as well as visits to sites which have been or are being treated for increased water yield were made to help insure appropriate interpretation of the subject matter.
3. Potential management opportunities for water yield improvement are evaluated in terms of (a) increased water yield, (b) implementation constraints dictated by changes in the production and use of other natural resources, (c) economic considerations, (d) institutional constraints, and (e) the impact of management practices on the long term quality of the environment.
4. Future research and operational alternatives for the Arizona Watershed Program are suggested as a result of the above analysis.

RIPARIAN ZONE CHARACTERISTICS

Definitions

A "riparian association" is defined by Lowe (1964, p. 62) as a vegetal association "which occurs in or adjacent to drainageways and/or their floodplains and which is further characterized by species and/or life forms different from that of immediately surrounding non-riparian climax." All species along a stream channel are not necessarily confined to this zone, but may be indigenous to the semi-arid environment of slopes adjacent to channels. Thus, Campbell and Green (1968) applied the term "pseudo-riparian" to woody plants that complete their life cycle in relatively xeric or mesic sites, but which achieve maximum size and density when additional subsurface moisture is available.

A phreatophyte was defined by Meinzer (1923, p. 55) as "a plant that habitually obtains its water supply from the zone of saturation, either directly or through the capillary fringe." The term, derived from two Greek words, means "well plant." Phreatic vegetation zones are found along the major rivers in Arizona at relatively low elevations where a shallow ground water table is conducive to establishment and survival of phreatophytic species. Separating riparian plants from phreatophytes is difficult,

and Horton (1969) believed it to be academic. Both plants require more water than is available by normal rainfall and neither have specialized organs for obtaining it. Riparian plants depend largely on flowing water and phreatophytes on ground water, but there is no clear division between shallow alluvial deposits in mountain streams for storage of ground water and deeper deposits in typical phreatophyte zones (Horton 1972). For purposes of this report, phreatophytes growing in the channels and floodplains of Arizona's major rivers are considered riparian vegetation.

"Hydrophytes" are plants that grow submersed, partly submersed, or floating in lakes, ponds, streams, or marshes. According to Northen (1958), hydrophytes usually have a scanty root system, a small amount of water-conducting and supporting tissue, and an abundance of tissue for conducting and storing air.

Vegetation

In Arizona, three "riparian association" delineations, specified by elevation, are recognized (Campbell 1970). For the purpose of this report, the vegetation characteristics of the riparian zone are presented in terms of these delineations: less than 3,500 feet, from 3,500 to 7,000 feet, and from 7,000 to 10,000 feet above mean sea level.

Less than 3,500 Feet Elevation

In this zone, many ephemeral streams have broad floodplains and terraced bottoms that support high densities of deep root shrubs and trees, such as mesquite (Prosopis juliflora Swartz D.C.), paloverde (Cercidium floridum Benth.), catclaw acacia (Acacia greggii Gray), burrobrush (Hymenoclea monogyra Torr. and Gray) and wolfberry (Lycium andersonii Gray). From 2,500 to 3,500 feet, cottonwood (Popuius fremontii Wats.) and sycamore (Plantanus wrightii Wats.) sometimes codominate with acacia and mesquite forming separate synusie (Campbell 1970). Surface flows occur only during flooding or after the alluvial aquifer is full or nearly full.

In deep canyons sheltered from direct radiation, riparian species may invade from higher elevations to become isolated communities similar to those at elevations up to 5,000 feet. On these sites, surface water is usually apparent most of the year (Campbell 1970).

Recurring floods, erosion, and sediment deposition cause large-scale changes in plant habitats, and thus influence the vegetation complex. Because of this vegetation flux, Campbell and Green (1968) found many species in immature stages of development commonplace on Sycamore Creek, Arizona, and concluded that riparian species probably never reach a climax hierarchy because of recurring floods and the resultant erosion and sediment deposition.

Six plant communities described by Haase (1972) in a survey of the lower Gila River floodplain may be considered typical of the low elevation water courses of central or western Arizona. These are: (1) cattail (Typha), (2) saltcedar-arrowweed (Tamarix-Pluchea), (3) mesquite (Prosopis), (4) seepweed-picklewood (Suaeda-Allenrolfea), (5) saltbush (Atriplex), and (6) creosote-mesquite (Larrea-Prosopis). The cattail community is found primarily in low areas of main channels. The saltcedar-arrowweed community is found principally in the lowest bottomlands on soil of undifferentiated alluvium subject to varying periods of surface moisture. Saltcedar-arrowweed may also occur where depth to ground water is shallow regardless of soil texture (Marks 1950). The mesquite community is found above the lowest bottomlands on non-saline or slightly saline soil (Haase 1972). The seepweed-pickleweed community is found on sites of moderately to strongly saline and somewhat heavier textured soil on floodplains. The saltbush community is located on the drier upper terraces, interspersed with and outward from the mesquite community. The creosote-mesquite community is generally found in the non-saline transition between floodplain and mesa regions on relatively dry and light or stoney soils. Variations of these floodplain communities are found throughout Arizona depending on such factors as amount of precipitation, depth to

ground water, soil salinity, soil texture, occurrence of freezing temperatures, and frequency of flooding.

Saltcedar (Tamarix pentandra Pall.) has spread rapidly along major rivers and floodplains of Arizona following its introduction into the United States about 1884 (Robinson 1958). It is the dominant plant cover in many cases and appears to draw heavily on the ground water supplies in addition to impeding flood waters. Saltcedar thickets (or tamarisk) also provide habitat for many species of wildlife.

Saltcedar is deciduous and has two growth forms, either a large shrub or a small tree, 10 to 30 feet tall, resembling a juniper. Stems support slender, contorted branches which are covered when young by small scale-like leaves. Branches are thick enough to form a dense foliage (Tomanek and Ziegler 1962).

Tamarisk is a prolific seeder during a blooming period from April through September. When moistened, the seeds usually germinated in less than 24 hours (Horton, Mounts, and Kraft 1960). The fresh seed of tamarisk often shows 100 per cent germination under laboratory conditions (Horton 1960). The seeds also germinate well in saline solutions which would be unfavorable for some competing vegetation (Hulett and Tomanek 1961). Under natural conditions, the seeds germinate on wet soil or on water surfaces. Germinating seedlings float to the water's edge where

conditions are suitable for establishment. As the water slowly drops during receding flood flows or during reservoir drainage, large areas are sown with tamarisk (Horton 1960).

The above ground parts of tamarisk produce roots and shoots if buried in moist soil. If the shrub is burned or cut at or near ground level, the root crown will produce vigorous sprouts, which may reach a height of ten feet in one season (Gary 1960). In cutoff stands, van Hylckama (1970) found that tamarisk shoots increased in length by as much as five cm per day under favorable conditions. Severed stems and shoots will also produce vigorous shoots and roots if buried in moist soil. Tamarisk plants have been known to survive ponding above the root crown for several weeks, but submergence of the entire plant for more than a few hours is usually fatal (Lowry 1957). Tamarisk plants are comparatively tolerant of saline and sodic soils and high water tables, and can survive cold weather and long periods of scant water supply (Lowry 1957). Potential competitors may be suppressed by salts exuded from a gland on saltcedar (Friedman, Shapira, and Waisel 1965).

3,500 to 7,000 Feet Elevation

Riparian areas within the 3,500 to 7,000 feet elevation zone contain the greatest number of species and the greatest foliar cover compared to the other "riparian association" delineations (less than 3,500 feet and from

7,000 to 10,000 feet elevation) (Campbell 1970). Cottonwood, willow (Salix spp.), sycamore, ash (Fraxinus velutina Torr.) and walnut (Juglans major (Torr.) Heller) are typical trees on floodplains. Often three or four of these species may occur together, and occasionally all five. All are large, winter-deciduous broadleaf trees of genera and families different from those of the immediately bordering non-riparian climax desert or grassland communities (Lowe 1964). Various species of oak (Quercus spp.) and alder (Alnus spp.) are also found in this zone.

Fremont cottonwood (Populus fremontii S. Wats) is the common species below 6,000 feet while narrow leaf cottonwood (P. angustifolia James) is found at elevations of 5,000 to 7,000 feet (Little 1950). Fremont poplar is a large tree, 50 to 100 feet tall, with trunk two to four feet or more in diameter and with a broad, flat, open crown of large branches. Narrow leaf poplar is a smaller tree, 50 feet in height and 1-1/2 feet in trunk diameter, with a narrow crown and slender erect branches. The total acreage and volume of cottonwood is not large. Barger and Ffolliott (1971) estimated that cottonwood occupies not more than 6,000 to 8,000 acres in the state. Cottonwood is distributed throughout Arizona, with major concentrations in the Verde, Little Colorado, and Gila River drainages.

Arizona sycamore obtains a height of 40 to 80 feet and a diameter of four feet or more; it has a broad, open

crown with large spreading branches. Sycamore reproduces predominately from root or stem sprouts. The species characteristically forms clones more or less equally spaced on floodplain terraces and occasionally within the channel proper.

Little (1950) listed eleven species of willow found along Arizona streams. They range from small to medium sized trees 20 to 50 feet in height with trunks one to three feet in diameter, to shrubs 6 to 15 feet tall with clustered stems.

Velvet ash and Arizona walnut are small to medium sized trees, 30 to 50 feet tall with one to two foot trunk diameters. Both have spreading branches and a rounded crown.

7,000 to 10,000 Feet Elevation

Above 7,000 feet, willow, alder, southwestern chokecherry (Prunus serotina virens Woot. & Standl.), boxelder (Acer negundo L.) and Rocky Mountain maple (Acer glabrum Torr.) predominate along stream channels. Surface water is perennial, and grasses and sedges border the relatively stable channels.

Climate

Arizona has a wide range of climatic conditions as a result of large differences in altitude, and a considerable

variation in latitude and the distribution of mountain ranges and highlands.

A Steppe climate occurs from the southeastern portion of Arizona northwestward into the northwestern portion of the state (Lower Colorado Region Comprehensive Framework Study, Appendix V 1971). Desert climate predominates over the southwestern quarter of Arizona. The area south of the Mogollon Rim is classified as Warm Temperature climate while higher elevations along the Rim have a Cold Temperate climate. North of the Mogollon Rim and at slightly lower elevations there is a transitional zone between the Cold Temperate and Steppe climates.

At relatively low elevations (0-3,500 feet), the average annual precipitation ranges from approximately four inches in the lower Gila and Colorado River drainages to about nine or ten inches in the Salt River floodplain near Phoenix (Haase 1972, Gary 1965). Rainfall is bi-seasonal and generally occurs as heavy thundershowers of short duration during July, August, and September, and as light showers of longer duration and somewhat greater seasonal amounts in winter (Green and Sellers 1964). Mean summer and winter temperatures of 80°F and 45°F, respectively, occur within this elevation zone (Green and Sellers 1964).

At elevations between 3,500 and 7,000 feet average annual precipitation ranges from ten inches up to 30 to 35 inches (Green and Sellers 1964). Late summer convectional

storms cause periodic flooding and high sediment movement, while winter precipitation is generally from low intensity and long duration storms, primarily in the form of rain below 4,000 feet and snow and sleet at higher elevations. Mountain ranges that rise above 7,000 feet may receive eight to 11 feet of snow in some years. Generally, however, there is less than four feet of snow during a normal year (Green and Sellers 1964). Within this elevation zone mean summer temperatures are approximately 65°F and mean winter temperatures vary from 45°F to 25°F depending on elevation.

High rates of evaporation and transpiration occur within Arizona due partly to a combination of high radiation and high air temperatures and low humidity. The annual evaporation rate from pans varies from about 50 inches in northeastern Arizona to 86 inches along the lower Colorado River (Lower Colorado Region Comprehensive Framework Study, Appendix V 1971).

The length of growing season in Arizona is variable and depends on the local elevation and the nature of surrounding terrain. Based on the 32°F temperature threshold, the growing season may be as short as 60 days in the mountainous areas and as much as 300 days or longer in the Yuma area (Lower Colorado Comprehensive Framework Study, Appendix V 1971).

Hydrology

Arizona can be divided into three principal water producing regions: (1) the plateau uplands of the northern part of the state, (2) the mountainous central highlands that extend diagonally across the state, and (3) the basin and range lowlands or deserts (Fourth Arizona Town Hall on Arizona's Water Supply 1964).

Except for the main stem of the Colorado River, almost all perennial streams that flow across the plateau uplands originate in the central highlands. Many streams become intermittent as they fan out in braided channels away from the mountains and runoff is dissipated by evapotranspiration or sinks into the highly fractured Kaibab limestone. Runoff from the plateau uplands is generally less than 0.3 inch, except in the headwaters near the Mogollon Rim.

Streamflow is perennial in the central highlands. However, runoff varies widely because of differences in precipitation, temperature, and terrain. In the Mount Baldy area of the White Mountains, the average annual runoff is about four inches (Fourth Arizona Town Hall on Arizona's Water Supply 1964). The average annual runoff for the Salt River system above Roosevelt Lake is 2.8 inches. The Verde River runoff averages 1.4 inches annually above its confluence with the Salt River. In the southern portion of the Central highlands, San Francisco and San Carlos

Rivers and Eagle Creek jointly contribute 0.6 inch of runoff annually to San Carlos Lake above Coolidge dam.

Average runoff from the driest 15,000 square miles in the lowlands is less than 0.1 inch (Fourth Arizona Town Hall on Arizona's Water Supply 1964). The headwaters of the San Pedro, Santa Cruz, and other large tributaries yield only about 0.5 inch per year. Flowing surface water is uncommon here except during periods of irrigation runoff or when infrequent flows occur as a result of precipitation. Ground water levels in and adjacent to channels fluctuate throughout the year and may be anywhere from zero to 30 or 40 feet deep.

Edaphic

At higher elevations soils of riparian zones generally consist of alluvial sediments derived from the surrounding mountains. In some areas, the stream channel may be cut on bedrock. In other cases, pockets of alluvium may alternate with exposed bedrock. Soil depth varies depending on stream gradient, topographic setting, and lithology of the source areas. In wide alluvial valleys or gently sloping plateaus, soil depth is generally greater than in incised canyon bottoms.

Soils on lower elevation floodplains are all of recent deposition with little visible development (Marks 1950). In the channels of all the major rivers of Arizona,

the alluvial soils are subject to frequent flooding and are usually stratified. Soils range in texture from very gravelly or cobbly sand to clay. In many places, the soil is strongly saline and/or strongly sodic. On the low terraces and in the wider portions of river valleys less subject to flooding, soil of finer texture occurs. These soils include the Vinton, Gila, Comoro, Pima, Gilman, Antho, Pimer, and Anthony series which range in texture from moderately coarse to moderately fine (USDA Soil Conservation Service 1969, 1971a, 1971b, 1972).

Physiographic

Arizona is comprised of almost 114,000 square miles, of which only 334 square miles are water surface (USDI Bureau of Reclamation 1965a, 1965b). The state is a complex of plateaus, mountains, deserts, and plains, with elevations ranging from about 100 feet to 12,611 feet above sea level.

The Plateau Province and the Basin and Range Province, two of the major physiographic provinces of the southwestern United States, are found within the state. A Transition Zone trending northwest-southeast across the center of the state separates these provinces. Individual plateaus with valley, buttes, and flat-topped mesas make up the Colorado Plateau Province which occupies the northern section of the state.

The Basin and Range Province in the south and western portions of Arizona consist of isolated mountain blocks jutting from alluvial sediments that form the broad desert basins.

A distinctive feature in the Transition Zone is the Mogollon Rim which extends more than 200 miles across the state and ranges in height from several hundred to more than 2,000 feet. This escarpment forms the divide between the Little Colorado and Gila River drainage systems. The Transition Zone has more relief than the other provinces because headward erosion of major streams has carved it into deep canyons and steep mountains.

Riparian sites in Arizona may vary from narrow bottom, deep steep-walled canyon bottoms to intermediately exposed sites with at least one terrace or bench to exposed wide valleys with meandering streams.

Wildlife and Fisheries

Riparian zones, particularly in Arizona, provide prime habitat for wildlife. Thus watershed management treatments, which remove or disrupt riparian vegetation in order to increase water yield, may adversely affect several species of wildlife and fish.

Bristow (1968, p. 43) has stated that "riparian vegetation is the key or nucleus of desert habitat." Saltcedar stands can provide excellent nesting habitat for

both mourning doves (Zenaidura macronura marginella) and whitewing doves (Melopelia asiatica mearnsi). Bottomland vegetation also serves as habitat for other game and non-game species. Quail, rabbits, songbirds, and waterfowl depend on the heavy vegetation for escape, nesting or roosting. Big game such as javelina, mule deer, and an occasional bear utilize riparian thickets as a refuge. According to Todd (1970), riparian vegetation at the lower elevations contain the widest variety and number of birds found in any natural habitat in Arizona, or of any inland habitat in Western North America. Higher elevation riparian communities along perennial streams also provide important habitat for game and non-game wildlife.

According to Minckley (1969), about 85 species of fish occur in Arizona. Approximately 25 species provide sport fishing. The others are of value as forage fishes, as pollution indicators, and for scientific investigations. Deep rooted riparian vegetation along streams aids fish habitat by stabilizing steep banks, preventing siltation, and by providing cover where roots are exposed in undercuts. Because they shade still pools, riparian communities may prevent high water temperatures and algal blooms.

Recreation

Surveys by the Outdoor Recreation Resources Review Commission found that the availability of water was a prime

factor in the enjoyment of most outdoor recreation (Poppleton 1968). The higher elevation riparian zones are particularly attractive for camping, picnicking, hiking, bird watching, and fishing. The river bottom and flood plains of the relatively low elevation rivers also known as "green belts" provide outlets for a number of recreation activities. Vegetation removal or channelization may adversely affect recreation activities in riparian zones. Along the Gila River from Granite Reef Dam east of Mesa to Gillespie Dam, numerous reconnaissance trips were made to determine the extent of non-hunting visitor use (Poppleton 1968). A relatively high incidence of use was noted throughout the year. Hunting, sightseeing, photography, bird watching, hiking and target shooting were the activities most often observed.

Perennial streams at higher elevations in Arizona which provide running water, lush vegetation, high animal and bird populations, and surrounding mountainous terrain have a high aesthetic appeal. The greenery produced by riparian vegetation in relatively low level floodplains of Arizona may provide variety and contrast to what otherwise may be a drab visual scene, particularly when viewed at a distance.

Ownership Patterns, Land Histories, Management Status

Knowledge of ownership patterns, land history, and management status is prerequisite to implementation of potential water yield improvement practices in the riparian vegetation zone.

Ownership Patterns

The riparian vegetation type is scattered along drainages, stream channels, and associated floodplains throughout Arizona in relatively narrow strips. When riparian vegetation is included on vegetation cover maps, it usually is not accurate because of problems with scale and its changeable nature. The areal extent of riparian communities may change rapidly as a result of flooding, declining water tables, man's activities, or the rapid invasion and expansion of species such as saltcedar.

The USDI Geological Survey periodically compiles the acreage of phreatophytes for different parts of the Southwest. Presently an estimated 279,600 acres are classified as riparian vegetation in Arizona (Table 1). These data, however, are collected by many government agencies concerned with phreatophyte control in local areas, and there is little uniformity in the mapping and evaluation procedures between the reporting agencies.

The Lower Colorado Region Comprehensive Framework Study, Appendix VI (1971) estimated that 320,000 acres of

Table 1. Location and areal extent of phreatophytes and hydrophytes in Arizona (Babcock 1968).

Location	Area (acres)
Colorado River Drainage:	
Main stem--Davis Dam to international boundary	111,000
Little Colorado, Virgin, and Will Williams Rivers, Kanap Creek, and Big Sandy Wash	28,200
Total	139,200
Gila River Basin:	
Duncan Valley	1,800
Cactus Flat-Artesia area	300
Safford Valley	6,600
San Carlos Indian Reservation area	9,200
San Carlos River valley	2,400
Coolidge Dam to San Pedro River	1,100
San Pedro River valley	23,600
San Pedro River to Buttes damsite	3,100
Sacaton to confluence of Salt River	11,000
Confluence Salt River to Gillespie Dam	10,100
Gillespie Dam to Painted Rock Dam	10,600
Painted Rock Dam to Texas Hill	6,000
Texas Hill to Dome	6,800
Hassayampa and Agua Fria Rivers	5,000
Palomas Plain	3,100
Gila River basin total	100,700
Salt River Basin:	
Verde River below Barlett Dam	18,000
Confluence Verde River to Tempe	8,000
Salt River basin total	26,000
Minor Drainage Areas:	
Picacho Reservoir	1,400
Udall Reservoir-Carrizo Creek	200
Santa Rosa Wash-Pinal County	2,600
Douglas basin	4,500
Willcox basin	5,000
Minor drainage areas total	13,700
State Total	279,600

riparian vegetation were potentially available for water yield improvement practices in Arizona, a difference of 40,000 acres in comparison to the USDI Geological Survey's estimate of 279,000 acres. This figure (320,000 acres) excludes wilderness, primitive areas, national parks and other lands where land treatment measures are prohibited by law or regulation. More than 1300 miles of streams in Arizona have been suggested for possible inclusion in the Wild and Scenic Rivers System; any of these areas finally selected would not be available for treatment. In addition, many popular riparian recreation areas such as Oak Creek Canyon near Sedona and Sabino Canyon near Tucson are not feasible vegetation management areas for increased water, and would therefore lower the above estimate to some extent.

The variation between the two estimates of riparian vegetation acreage in Arizona given above (279,600 versus 320,000 acres) indicates that the total acreage of riparian vegetation within the State is imperfectly known. Therefore, these figures should be considered as rough approximations of the amount of riparian vegetation in Arizona.

Ownership of riparian lands in Arizona is poorly documented, with the exception of the Lower Colorado River from Davis Dam to the international boundary. The USDI Bureau of Reclamation, Three (1963) has detailed maps and records of land ownership along the Colorado River between

Davis Dam and the International Boundary with Mexico. The approximate total phreatophyte acreate by type of land ownership on the Arizona side of the River is presented in Table 2.

Table 2. Approximate total phreatophyte acreage by type of land ownership on the Arizona side of the Colorado River (USDI Bureau of Reclamation, Three, 1963).

Type of Ownership	Study Area in Acres
Private	14,850
State	1,250
Federal	17,170
Indian	89,060
Wildlife refuge (Federal)	9,310
Total	131,640

Detailed maps of the location and species composition of riparian vegetation, ground water depths, and location of arable and non-arable land are available for the Colorado River below Davis Dam (USDI Bureau of Reclamation, Three, 1963). This information was obtained in 1962. Although some additional data on phreatophytes have been gathered since that time, it has not been analyzed or mapped. However, the amount of riparian vegetation has remained

about the same except for some clearing on Indian reservations and in the development of recreation sites (Bowser 1973).

The Lower Colorado Region Comprehensive Framework Study, Appendix VIII (1971) indicated that approximately 106,000 acres of riparian vegetation in Arizona occur in blocks of "significant" size along the Gila, Salt and Colorado Rivers. The ownership of these areas is indicated in Table 3. This figure of 106,000 acres of riparian vegetation in Arizona is less than the 279,000 and 320,000 acres reported above. Apparently only riparian acres of large size, which were not defined, were considered in the Lower Colorado Comprehensive Framework Study, Appendix VIII (1971). On the other hand, the higher estimates (279,000 and 320,000 acres) included all riparian vegetation without regard to the size of area covered by phreatophytes.

Standards have been developed for the systematic mapping of phreatophytes by Horton, Robinson, and McDonald (1964), but no agency maintains a continuing systematic survey and evaluation of the changes in phreatophyte acreage (Babcock 1968). Up-to-date and continuous information on phreatophyte coverage possibly may be obtained in the future by use of the Earth Resources Observation System (EROS). Partly for this purpose, the USDI Geological Survey recently implemented the Resources and Land Information Program (RALI). The Tucson-Phoenix demonstration area, extending

Table 3. Land ownership and administration of riparian vegetation along the Gila, Salt, and Colorado rivers.

Land Ownership and Administration	Acres
Federal Land Administered by:	
USDA Forest Service	50,000
USDI Bureau of Land Management	7,000
USDI Bureau of Sport Fisheries & Wildlife	15,000
State	10,000
Individual or Corporate	22,000
Indian	2,000
Total	106,000

from the international boundary at Nogales, Arizona to the vicinity of Wickenburg, Arizona was mapped at scales ranging from 1:24,000 to 1:500,000 during 1973 utilizing satellite data. The information mapped included land ownership, land irrigated, land subsidence, flood-prone areas, depth to ground water, ground water quality, vegetation, and wildlife habitat zones.

Land Histories

Mountain riparian areas have not changed much in the recent past (Horton 1972). Some vegetation clearing and dam construction has occurred, but in general, vegetation along

mountain streams has developed with a minimum of disturbance by man.

In contrast, riparian zones along the major stream courses in Arizona have changed markedly since the arrival of non-Spanish white settlers. The writings of the Jesuit missionary Eusebio Francisco Kino (Bolton 1948) refers to environmental conditions circa 1700 on the lower Gila River. The Indian inhabitants were described as fishermen who used nets and tackle year around to sustain themselves with an abundance of fish. In 1846, cottonwoods along the lower Gila River were described as 25 to 30 feet high and the bottom land thickly overgrown with willow and a tall aromatic weed, with many signs of waterfowl, deer, and beaver. Nevertheless, the river bottom had local areas incrusted with salt and a number of salt lakes were found locally within the floodplain (Emory 1848).

The Gila River floodplain was a popular trans-continental route to California (Haase 1972). Pioneers and miners removed riparian woodlands for fuel, homes, fence-posts, and croplands. Early records indicate that all trees were removed from riparian areas close to human develop-ments (Horton 1972).

Development of irrigation technology brought about other large changes. Pumping and dam construction lowered ground water levels, which in turn reduced the density of riparian vegetation in and along stream channels. As a

result of less frequent destruction of vegetation by floods, a dense woody growth sometimes developed. In other cases, dams diverted surface water in critical growth periods, depriving riparian vegetation of moisture and thereby contributing to its destruction. In contrast, constant water flow in man-made channels and ditches created a suitable environment for growth of riparian vegetation where it had not occurred before (Horton 1972).

Disturbance of riparian vegetation by man provided favorable conditions for invasion of tamarisk into the Southwest; a process which began in the early 1900's. According to Robinson (1967), tamarisk has replaced native vegetation on an estimated one million acres of western floodplains.

Management Status

Permanent streams are relatively few in Arizona and most are heavily used for recreation. Woods (1966) classified permanent streams as a scarce resource because studies showed that the Southwest Region of the USDA Forest Service has 11 per cent of the land area but has only about two per cent of the total mileage of fishing streams reported in the National Forest System.

Conflicts and competition for the use of riparian resources and environments can be intense. Partly for this reason, a water influence zone is recognized in USDA

National Forest multiple-use planning and coordination program. A water influence zone is a unit of land that is dominately influenced by water. A water influence zone includes the water body and immediately adjacent land that interacts directly with the water body and which must be managed jointly with the water. Similarities in resource combinations and management opportunities lend themselves to establishment of a common management direction within a water influence zone. Waterfront zones have been established along most live streams in the Southwest by the USDA Forest Service. This zoning is a planning procedure used by the USDA Forest Service to carry out and implement the Multiple Use Act which directed that areas on National Forests be managed in order to yield the combination of uses best suited to the public needs. The purpose of zoning is to delineate the area where the coordinating requirements are carried out in resource management project plans and developments. Coordinating requirements direct the manner and degree to which one resource use or activity will be modified or intensified to resolve conflicts or enhance other resource values. The possibility of intensive management of streamside vegetation for increased water yield is not precluded. However, a greater number of multiple-use constraints must be complied with to satisfy multiple-use objectives than in other vegetation zones such as ponderosa

pine or pinyon juniper stands managed by the USDA Forest Service.

Management of mountain riparian vegetation is still in the experimental stage. Clearing by mechanical or chemical means was conducted on Cottonwood Wash and Sycamore Creek by the USDI Geological Survey in an attempt to determine the amounts of water transpired by riparian vegetation. The USDA Forest Service conducted limited riparian treatment studies on the Sierra Ancha Forest.

In contrast, more has been accomplished along the relatively lower major river courses in Arizona. The following survey (Table 4 and Figure 1) was prepared under the direction of the Pacific Southwest Inter-Agency Phreatophyte Subcommittee in 1969. Many of the planned projects shown in Table 4 are in litigation or in abeyance until environmental impact statements have been completed, reviewed, and approved.

Until the mid 1960's, the first goal of flood plain management was to control or completely eliminate undesirable phreatophytes for water salvage[1] and flood control.

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1. Water salvage, water savings, and water losses are biased terms used throughout this dissertation for lack of better terms to describe changes in evapotranspiration rates and amounts which occur after riparian vegetation has been manipulated. In reality the water from riparian zones can only be salvaged, saved, or lost in terms of its immediate use by man. In the strict hydrologic sense water is not saved or lost, but only changes from one state to another as it moves through the hydrologic cycle.

Table 4. Survey of phreatophyte treatments in Arizona by agency, location, vegetation type, acreage treated, and type of treatment used (Pacific Southwest Inter-Agency Committee 1969).

Agency Name	Map Figure 1	Location[a]	Vegetation Type[b]	Vegetation Method[c]	Acres of Work Completed	Acres of Work Current	Acres of Work Planned	Type of Treatment
Federal:								
Bureau of Indian Affairs Phoenix Area Office P.O. Box 7007 Phoenix, Arizona 85011	(1)	T-1S-2S; R-19E San Carlos River	C	V.S. P.	259	250	--	Dozing
		T-1S-2S; R-19E San Carlos River	M	V.S. P.	341	375	--	Knifing
		T-1S-2S; R-19E San Carlos River	T	V.S. P.	600	877	--	Knifing
		T-1S-2S-3S; R-19E-20E-21E-22E Gila River	M	V.S. P.	1714	6242	--	Knifing
	(2)	T-1S-2S-3S; R-19E-20E-21E-22E Gila River	T	V.S. P.	5140	5978	--	Knifing
	(3)	T-7N; R-18E-19E Cibecue	C	P. W.E.	843	843	--	Chemical
Bureau of Indian Affairs Navajo Reservation Tuba City Agency Tuba City, Arizona 86045	(4)	Little Colorado River within Navajo Reservation	T	--	--	--	Undetermined acreage & timing	--
Bureau of Indian Affairs San CArlos Irrigation Project Coolidge, Arizona 85228	(5)	T-2S-3S; R-20E Gila River	T	W.E.	44	--	101	Dredging
	(6)	T-4S-5S; R-13E-14D-15E Gila River	T	V.S.	10	--	2600	Mech. Removal Dozing, Knifing

Table 4.--Continued Survey of phreatophyte treatments in Arizona by agency, location, vegetation type, acreage treated, and type of treatment used (Pacific Southwest Inter-Agency Committee 1969).

Agency Name	Map Figure 1	Location[a]	Vegetation Type[b]	Vegetation Method[c]	Acres of Work Completed	Acres of Work Current	Acres of Work Planned	Type of Treatment
Bureau of Land Management 3022 - Federal Bldg. Phoenix, Arizona 85025	(7)	T-11S; R-29E; Sec. 23 San Simon	T M	W.E.	10	--	--	Knifing
	(8)	T-12S; R-29E; Sec. 2-11-12 San Simon	T M	W.E.	300	--	--	Knifing
	(9)	T-6N; R-12W; Sec. 14-15 Centennial Wash	T	W.E.	--	--	10	Knifing, Dozing
Bureau of Reclamation Phoenix Development Ofc. Region 3 135 North 2nd Avenue Phoenix, Arizona 85003	(10)	T-16 through 21N; R-15 through 22E Little Colorado River Winslow-Holbrook Div. Mogollon Project	C T	W.E.	(Planning initiated July, 1969. No field work accomplished toward identification of type or extent of vegetation.)			
	(11)	T-2N-3N-4N; R-6E-7E-8E Orme Reservoir Salt & Verde Rivers	C T M	W.E.				
	(12)	T-4N-5N; R-11 through 14E Buttes Reservoir Gila River	T C M	W.E.	Clearing of reservoir area of large growth to top of conservation storage that is considered an operational or safety hazard.			
	(13)	T-21S-22S; R-21E-22E Charleston Reservoir San Pedro River	M T	W.E.				
	(14)	T-14S; R-16W New Mexico Base Meridian - Hooker Reservoir - Gila River	C T S M	W.E.				

Table 4.--Continued Survey of phreatophyte treatments in Arizona by agency, location, vegetation type, acreage treated, and type of treatment used (Pacific Southwest Inter-Agency Committee 1969).

Agency Name	Map Figure 1	Location[a]	Vegetation Type[b]	Vegetation Method[c]	Acres of Work Completed	Acres of Work Current	Acres of Work Planned	Type of Treatment
	(15)	T-5 through 24S; R-15 through 22E San Pedro River	T M	V.S. P.	--	--	Planning Still in Progress 23,600 Ac.	
	(16)	T-1 through 21N & T-1 through 12S; R-17 through 25W Lower Colorado River Davis Dam to U.S. Mexico Border	T A M	V.S.	--	--	42,000	
	(17)	T-2 through 5S; R-28 through 32E Upper Gila & San Francisco Rivers above Corps of Engineers Camelsback Reservoir site (Arizona & New Mexico)	C T M	W.E.	--	--	Unknown	
	(18)	T-1 through 24S; R-1 through 14E Santa Cruz River	M	W.E.	--	--	Unknown	
Department of the Army Corps of Engineers Los Angeles District P.O. Box 2711 Los Angeles, Calif. 90053	(19)	T-4 through 7S; R-22 through 28E Gila River, Graham County, Brown Canal Heading to San Carlos Reservation	T M	V.S.	--	5250	--	Root plow - clear cut except for 100' fringe each side of channel.

Table 4.--Continued Survey of phreatophyte treatments in Arizona by agency, location, vegetation type, acreage treated, and type of treatment used (Pacific Southwest Inter-Agency Committee 1969).

Agency Name	Map Figure 1	Location[a]	Vegetation Type[b]	Vegetation Method[c]	Acres of Work Completed	Current	Planned	Type of Treatment
	(20)	T-4-5S; R-14-15E Gila River, Pinal County, Winkelman to Kelvin, Arizona	T M	V.S.	--	--	1950 (May be duplication of B.I.A. - San Carlos 2600 acre planned.)	Root plow - clear cut except for 100' fringe each side of channel.
	(21)	Gila River, Yuma County, Texas Hill to Gila Siphon	T M	V.S.	--	--	5300	Dozing, 100' fringe retained.
International Boundary & Water Commission United States & Mexico P.O. Box 1859 El Paso, Texas 79950	(22)	T-8-11S; R-24-25W A 700' strip of floodway - Colorado River, Morelos Dam to Mexican Boundary (21 river miles)	W M		1500	Annual Maintenance Discing of treated reach.		
State:								
Arizona Gam & Fish Dept. P.O. Box 9095 2211 West Greenway Road Phoenix, Arizona 85020	--	--	--	--	(Department reports ". . . an inventory of the type, density, and acreage of riparian growth on floodplains along streams in Arizona." Work covers 430 river miles considered as valuable for wildlife purposes; no treatment by A.G.&F. Dept.)			
Arizona State Parks Board 1611 West Adams Phoenix, Arizona	(23)	N 1/2 of Section 32; T-11N; R-18W Buckskin Mtn. State Park	T	--	50 (1965)	--	--	Dozing
University of Arizona College of Agriculture Department of Watershed Management Tucson, Arizona 85721	--	Growth-chamber study at University and field study.	T	--	--	--	--	Chemicals

Table 4.--Continued Survey of phreatophyte treatments in Arizona by agency, location, vegetation type, acreage treated, and type of treatment used (Pacific Southwest Inter-Agency Committee 1969).

Agency Name	Map Figure 1	Location[a]	Vegetation Type[b]	Vegetation Method[c]	Acres of Work Completed	Acres of Work Current	Acres of Work Planned	Type of Treatment
County:								
Office of the County Engr. Apache County P.O. Box 72 St. Johns, Arizona 85936	(24)	Sec. 27; T-13N; R-28E Little Colorado River	T W	W.E.	4	--	--	Dozing
Office of the County Engr. Graham County Board of Supervisors Graham County Court House 800 Main Street Safford, Arizona 85546	(25)	T-5-7S; R-24-27E The middle Gila River channel, Graham County (35 river miles)	T M	P.	--	--	500+	Dozing, Chaining, and Burning
Office of County Engr. Greenlee County Board of Supervisors Clifton, Arizona 85533	(26)	Gila River through Clifton	C	W.E.	Snags in channel which had to be removed in connection with Corps of Engineers' file 448/129 - 1967			Mech. Removal
Maricopa County Flood Control District 3325 West Durange St. Phoenix, Arizona 85009	(27)	T-2N; R-5E to T-1N; R-2E Salt River Channel Maricopa County - Country Club Dr, (Mesa) to 59th Avenue	T	W.E.	Planned with Corps of Engineers; execution by private parties without reference to plan. Channel improvement pending.			Mech. Removal
	(28)	T-1N; R-1E to T-2S; R-5W 91st Avenue to Gillespie Dam,	T W	W.E.	Planned, authorized but pending due to conflicts within state and between federal agencies.			Mech. Removal
Office of County Engr. Mohave County % N. J. Devlin, Consulting Engineer P.O. Box 431 Kingman, Arizona 86401	(29)	Sec. 12; T-20N; R-22W Colorado River	T M	P.	15	--	30	Dozing

Table 4.--Continued Survey of phreatophyte treatments in Arizona by agency, location, vegetation type, acreage treated, and type of treatment used (Pacific Southwest Inter-Agency Committee 1969).

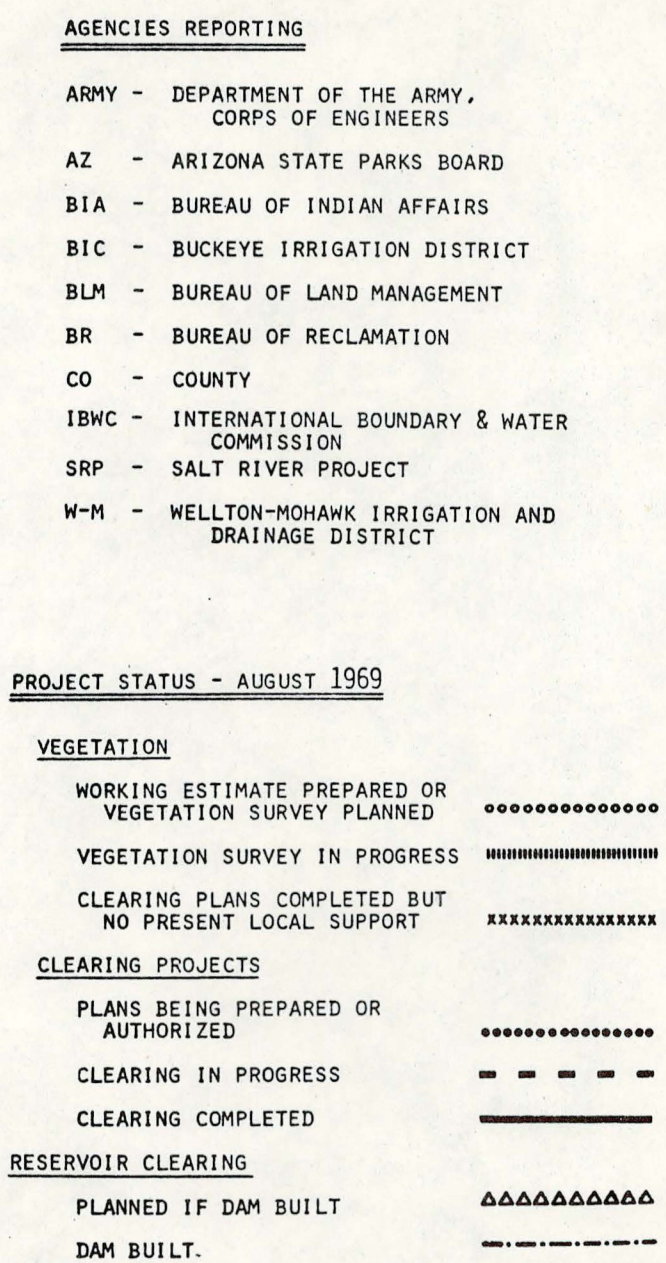
Agency Name	Map Figure 1	Location[a]	Vegetation Type[b]	Vegetation Method[c]	Acres of Work Completed	Acres of Work Current	Acres of Work Planned	Type of Treatment
Irrigation Districts:								
Buckeye Irrigation Company P.O. Box 726 Buckeye, Arizona 85326	(30)	Parts of Secs. 27-28-33; T-1N; R-1W. Agua Fria River Channel at confluence with Gila River	T	W.E.	40 to 50 Maintenance Only (July, 1968)			Dozing, Discing
Colemenero Canal Company #1 % R. Golding Duncan, Arizona 85534	--	--	C T W M	W.E.	(Canal not in use at present time)			Dozing, Chemicals
Salt River Project P.O. Box 1980 Phoenix, Arizona 85001	(31)	T-13-16N; R-3-5E, along Verde main-stream, and tributaries to east, 44 river miles	C T W	W.E. P.	1029	-- (FY '70-'75)	1500	Dozing, Sawing
San Carlos Irrigation & Drainage District P.O. Box 218 Coolidge, Arizona 85228	--	--	--	--	Maintenance of work by B.I.A. - future (FY '71-'72)		--	
Wellton-Mohawk Irrigation & Drainage District Route 1, Box 19 Wellton, Arizona 85356	(32)	T-5 through 9S; R-11 through 19W Gila River Channel, Hyder to Wellton 50 river miles	T	W.E.	--	600	--	Dozing, Spraying, Disc Plowing

[a] All locations are on the Gila and Salt River Base Line and Meridian unless otherwise noted.

[b] C = cottonwoods; M = mesquite; T = saltcedar; S = sycamore; W = willows.

[c] Method of identification; V.S. = vegetative survey; P = photographs; W.E. = working estimate.

Figure 1. Location of phreatophyte treatment areas in Arizona by agency and project status (Pacific Southwest Inter-Agency Committee 1969).


AGENCIES REPORTING
ARMY - DEPARTMENT OF THE ARMY, CORPS OF ENGINEERS
AZ - ARIZONA STATE PARKS BOARD
BIA - BUREAU OF INDIAN AFFAIRS
BIC - BUCKEYE IRRIGATION DISTRICT
BLM - BUREAU OF LAND MANAGEMENT
BR - BUREAU OF RECLAMATION
CO - COUNTY
IBWC - INTERNATIONAL BOUNDARY & WATER COMMISSION
SRP - SALT RIVER PROJECT
W-M - WELLTON-MOHAWK IRRIGATION AND DRAINAGE DISTRICT
PROJECT STATUS - AUGUST 1969
VEGETATION
WORKING ESTIMATE PREPARED OR VEGETATION SURVEY PLANNED
VEGETATION SURVEY IN PROGRESS
CLEARING PLANS COMPLETED BUT NO PRESENT LOCAL SUPPORT
CLEARING PROJECTS
PLANS BEING PREPARED OR AUTHORIZED
CLEARING IN PROGRESS
CLEARING COMPLETED
RESERVOIR CLEARING
PLANNED IF DAM BUILT
DAM BUILT.

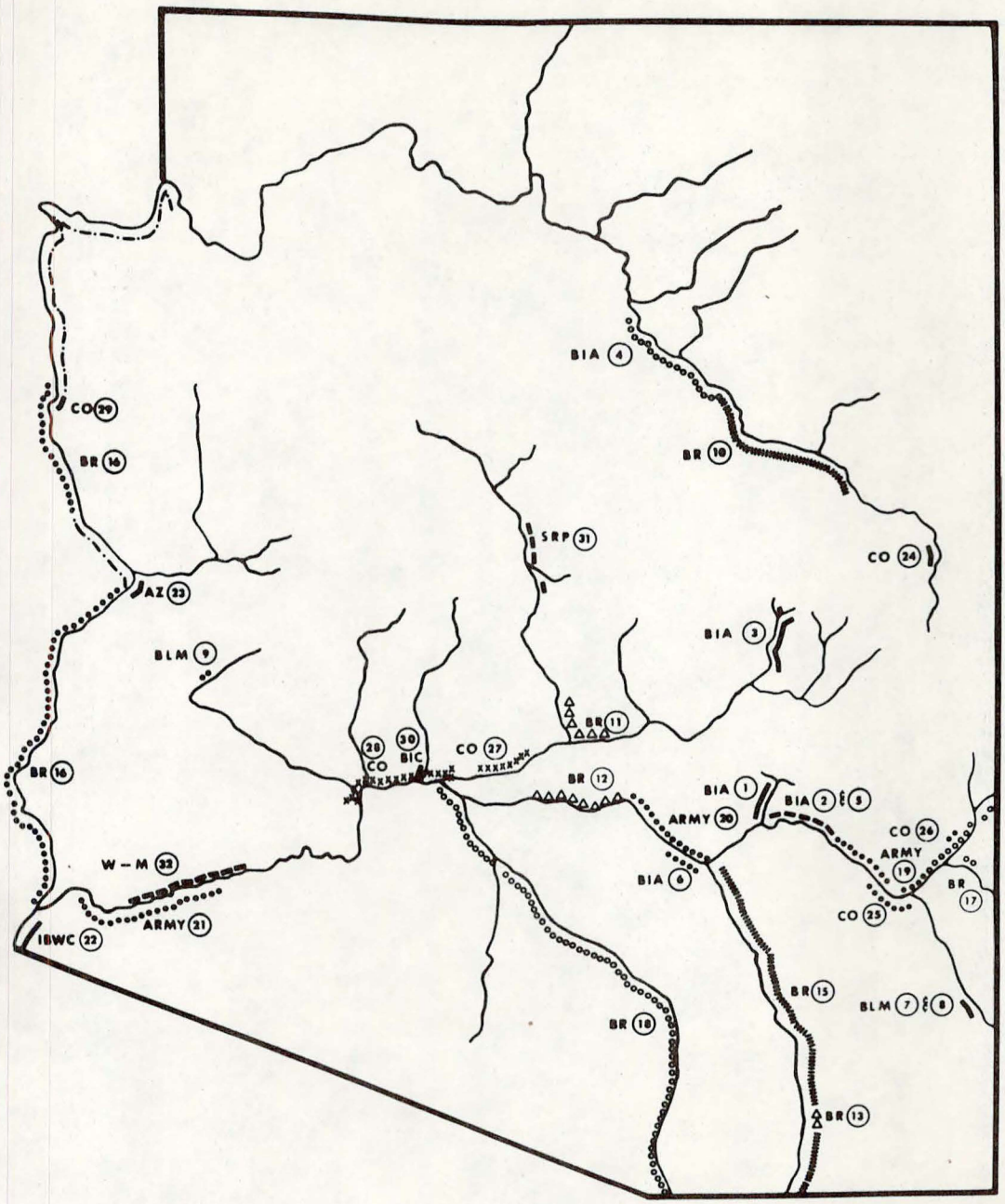


Figure 1. Location of phreatophyte treatment areas in Arizona by agency and project status (Pacific Southwest Inter-Agency Committee 1969).

However, pressure by environmental groups and the general public to preserve and develop these areas for wildlife, recreation, and aesthetic values coupled with the requirement for producing environmental impact statements has brought most of the planned treatment programs to a halt. For example, the USDI Bureau of Reclamation abandoned all plans for treating phreatophytes on the San Pedro and Santa Cruz floodplains (Lillard 1972).

WATER YIELD IMPROVEMENT OPPORTUNITIES

Conversion

Conversion of riparian vegetation on floodplains to other cover types which transpire less water has been practiced since the early 1950's. By either mechanical or chemical treatments, or a combination of these, riparian vegetation is completely eradicated from within the channel and on the floodplain. Following this operation, the area is usually treated on one of three ways. The first and most common practice is to suppress the reinvading riparian vegetation by means of an annual mechanical or chemical maintenance program. Annual grasses, weeds, and shrubs of low water using capacity are allowed to invade the cleared floodplain. In the second type of follow-up treatment, grasses adapted to semi-arid conditions are seeded and then managed intensively for herbage production. The seeded grasses may decrease annual maintenance costs by competing with reinvading riparian vegetation, and may decrease soil erosion by water and wind. However, this seeding technique may be limited to sites where the water table is within reach of the grass species to be established. In the third type of conversion program, the floodplain is converted to irrigated cropland.

Bulldozers, rootplows, rock rakes, discs, rotary mowers, and hand-clearing tools are used for mechanical clearing. Often this equipment is used in various combinations depending on variations in the size and density of the vegetation, and on terrain and soil conditions. To obtain effective mechanical control of sprouting species, particularly tamarisk, the root crowns must be severed from the root system and the tops must be dried before they can take root. After initial clearing, vegetation must be windrowed or piled, and burned to facilitate treatment of reinvading riparian species. Hand-clearing is often used along perennial streams at higher elevations to prevent soil disturbance and subsequent erosion.

Aerial chemical sprays on dense, mature phreatophytes in most cases have been ineffective. Greater success has been attained by mechanically removing mature vegetation and spraying the regrowth. Young actively growing vegetation is more susceptible to herbicides than older plants, and better spray coverage of foliage can be obtained. Herbicides are applied by aerial or ground equipment four to six months after initial mechanical clearing when regrowth is young, succulent, and actively growing. These applications must be repeated annually to maintain good control of woody regrowth and to encourage reinvading grasses.

In a recent development, mechanical clearing and chemical application were combined into one operation known

as "chem-cut." In this operation, herbicide is applied when the brush is being cut by a rotary mower. For large mature growth, experiments have been conducted with the "chem-plow" (Hollingsworth, Quimby, and Jaramillo 1973). In this operation, the trailing edge of a root plow is equipped with a spray boom from which a herbicide solution can be applied as the roots are severed at selected depths below the surface. The chem-cut and chem-plow methods avoid damage to susceptible crops growing in the area, which can occur when aerial or ground spraying equipment is used. However, contamination of runoff water may be possible when large areas of land are treated with herbicides by the chem-cut and chem-plow methods near river channels and floodways.

Justification for Water Yield Improvement

The potential for increasing water yields by manipulating riparian vegetation in the Southwest has been held in high regard by water interests for a number of reasons. The apparent high transpiration rates of plants growing in an arid environment with their roots extending into the water table or capillary fringe was perhaps the major reason for initial optimism on the part of investigators. The rapid invasion of floodplains by tamarisk, a high water-using phreatophyte which formed dense, impenetrable thickets, created further interest. Phreatophytes

growing in channels can also block flood flows and cause damage by forcing the water out on developed floodplains, thus providing another reason for eradication. In addition, land managers engaged in eradication programs believed that phreatophytes were of low economic value and were "water wasters" (Horton 1966). However, more recently, the value of phreatophyte vegetation zones for wildlife, recreation, and aesthetic purposes has received increasing attention by segments of the public.

Because water is concentrated in or below river channels and close to its source of use (irrigated agriculture on the floodplains or municipalities) there may be relatively low transmission losses between the points of conversion treatments and use. Finally, Arizona is considered by many as a water deficient state at a time when there is a growing demand for water because of population, industrial growth and declining water tables.

For these reasons, studies of water use by riparian vegetation in the Southwest have been conducted over a period of many years. Methods of eradicating phreatophytes by chemical means have also been investigated. These studies and their results are discussed below.

Studies of Water Use by Riparian Vegetation

For purposes of discussion, studies of water use by riparian vegetation have been classified into six categories

including evapotranspiration tank studies, evapotranspiration tent studies, studies based on water table fluctuations, model studies, climatological methods, and aerodynamic and energy budget methods. In general, water use studies are a mélange, involving many different agencies, locations, species, and techniques. In many cases these water use studies have little relationship to one another. Therefore, it is difficult to determine the actual quantities of water being transpired by riparian vegetation zones in Arizona. Only patterns or trends in water use by riparian communities can be obtained from the water use studies discussed below.

Evapotranspiration Tank Studies. An evapotranspiration tank, also known as an evapotranspirometer or tank, is usually a steel, concrete, or polyvinyl tank filled with soil and provided with a water supply in which plants are grown. Evapotranspiration is computed as the amount of water added to maintain the water level at a constant depth below the surface of the tank.

Water losses determined by the tank method should be interpreted with care. In all tank methods, the plants are growing in an unnatural environment. The soil is generally disturbed in construction of the tank, and because natural drainage is not possible, salts accumulate in the tanks unless removed by artificial drainage. In general, young, vigorous plants are grown in tanks with more shallow water

tables than are usually found throughout a floodplain. In addition, the density of plants in the tanks may be greater than the average density of similar vegetation growing in floodplains. Water levels in tanks are maintained at a constant level and the water table under natural conditions may fluctuate in response to rainfall, snowmelt or irrigation runoff and may decline in the summer months. Plants of different species grow in mixed stands and at varying densities, further complicating the problem of determining water loss. Some tank studies were conducted for only one year when the plants were young and growing vigorously. Other tank studies ran for longer time periods, and water use measurements were not made until the riparian vegetation was more mature. Thus no direct comparisons of water use can be made between young, immature plants of short term tank studies and more mature plants of longer term tank studies according to Horton and Campbell (1974).

Some tanks, particularly in early studies were open to the effects of radiation and wind (oasis effect) and thus plants grown in them may have had higher transpiration rates than plants growing in natural riparian vegetation communities. Van Hylckama (1968) reported that the artificially maintained ground water level in plastic lined tanks was influenced by barometric pressure which was out of phase with the diurnal fluctuations caused by transpiring plants. Thus, if the influence of barometric pressure on water

levels in the tanks is not accounted for, errors in the transpiration measurements of riparian species may result. Finally, the extrapolation of tank evapotranspiration measurements to field conditions by the volume density method may be in error. The Hydrology Subcommittee of the Pacific Southwest Inter-Agency Committee (1967) stated that there is suggestive evidence that the transpiration rate by a particular species is somewhat greater at a cover density of about 90 per cent than at 100 per cent. At the small densities, a greater proportional rate would be expected, owing both to oasis effect and to the generally larger average foliage volume of isolated plants.

Even with these deficiencies, evapotranspiration tanks probably give the most accurate data of all the water use measurement methods described in this section. The tank method is frequently used as a control to check the accuracy of other methods used to measure transpiration by phreatophyte species such as the energy budget.

Study No. 1:

The USDI Geological Survey investigated the amount of water transpired by phreatophytes in Lower Safford Valley, Arizona along the Gila River, using 29 sunken soil tanks in 1944 (Gatewood et al. 1950). The annual water use in acre-feet per acre for growth of 100 per cent volume

density[2] was saltcedar 7.2, bacaharis 4.7, cottonwood 6.0, and mesquite 3.3. This information was then extrapolated to 9,303 acres of bottomland vegetation along the Gila River. Total annual use of water was then estimated to be 28,000 acre-feet (about 3 acre-feet per acre), a large portion of which scientists felt could be salvaged by eradication of the phreatophytes (Gatewood et al. 1950).

Study No. 2:

Six evapotranspirometers were installed by the USDI Bureau of Reclamation and the USDI Geological Survey and planted to saltcedar near Buckeye, Arizona on the Gila River floodplain. The tanks (33 feet square and 12 feet deep) were larger than the Safford tanks and constructed of vinyl plastic. In contrast to the Safford tanks, evapotranspiration losses were not measured until the third growing season at Buckeye. Thus, the saltcedar was nearly mature and more typical of the riparian vegetation found on natural floodplains. The annual water use by saltcedar for water table depths of five, seven, and nine feet was approximately 8.0, 4.6, and 3.3 feet, respectively (van Hylckama 1963). Results of the study indicated that saltcedar grew and developed rapidly in early spring and that water use

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2. Volume density is the product of the area of the canopy and the average height, sometimes corrected for crown depth. Standards and techniques for the volume determination are set forth by Horton et al. (1964).

increased concomitantly. Growth and development leveled off by mid-summer along with a reduction in water use, even though accessibility to ground water remained the same.

The assumption by Gatewood et al. (1950), that phreatophytes always transpire at a potential rate, is not valid, according to van Hylckama (1970). Van Hylckama (1970, p. 728) stated that

> when differences in depth to water as small as 1.5 to 2.1 meters and 2.1 to 2.7 meters affect the water use, it is reasonable to conclude that with a water table at four meters for instance (a situation not unusual along dry river beds), saltcedar still may thrive but use comparatively little water, and the claims as to the quantity of water potentially saved by their eradication could well be over estimated.

However, Horton and Campbell (1974) suggested that the accumulation of salts in the bottom of the tanks may have caused the reduction in evapotranspiration with increased water depth rather than increasing depth to ground water. Although there was a relationship between evapotranspiration and depth to ground water earlier in the study, it appeared to become more prominent over time as salts accumulated in the bottom of the tanks.

Effects of salinity and thinning to 50 per cent of the original stand density on water use by saltcedar were investigated at Buckeye (van Hylckama 1970). Total water use per year in tanks at the Buckeye project plotted against electrical conductivity of the saturation extract of soil samples taken from the root zones for three successive

years showed a statistically significant negative correlation, i.e., as salinity increased water use decreased.

In March 1955, the vegetation in two tanks was thinned to approximately 50 per cent of the original density and all vegetation in two other tanks was cut to a height of approximately two feet. The water use in the cut tanks was much less than that in the vegetated tanks; however, within two months, water use in the cut tanks increased sharply with regrowth of the vegetation. The thinning treatment did not produce significant decreases in water use. Van Hylckama (1970) concluded that the method of making a vegetation survey and then extrapolating water use as measured by evapotranspirometers to a 100 per cent volume density could lead to serious errors in the estimation of water use. If the volume density at the time of measurement is 50 per cent, then it is assumed that the water use under 100 per cent conditions will be twice as much. This was not the case in the thinning experiment described above. The tanks deprived of 50 per cent of their transpiring surface used only ten to 15 per cent less water than the undisturbed control stand. By the same reasoning, if the investigator knows the amount of water lost from a 100 per cent volume density stand and divides this amount in half for areas with only 50 per cent volume density, his estimate of actual water losses will possibly be too low.

Study No. 3:

In 1961 the USDI Bureau of Reclamation and the USDI Geological Survey constructed 13 evapotranspirometers in the Colorado River floodplain near Imperial Dam to determine evapotranspiration losses from areas occupied by phreatophytes. Nine tanks (approximately 32 feet square and five to seven feet deep) were located within an extensive area of arrowweed which is the dominant species on much of the Colorado River floodplain. Three of the tanks were maintained free of vegetation; arrowweed was grown in three tanks; quailbrush (Atriplex lentiformis (Torr.) Wats.) was grown in two; and four-wing saltbush (Atriplex canescens (Pursh) Nutt.) was grown in one tank. Another group of four tanks (ten feet square and four feet deep) was located in the swampy margin of Mittrey Lake to estimate the evapotranspiration rate of a cattail environment.

Arrowweed used approximately 8.0 feet of water annually when the depth to water was maintained between five and six feet below land surface (Hughes and McDonald 1966). This indicates that arrowweed may use as much water as saltcedar. The average annual use of water by quailbrush and four-wing saltbush was, respectively, 3.0 and 2.4 feet with depths to ground water of 5.5 feet. Cattail used an average of 8.6 feet per year with roots submerged in water. Annual water use in the bare soil tanks for 1964 was 1.81,

0.60, and 0.37 feet for water table depths of 2, 3, and 4 feet, respectively.

Study No. 4:

Twelve tanks ranging in size from 30 feet square and 10.5 feet deep to ten feet square and seven feet deep were constructed in the Humbolt River Valley near Winnemucca, Nevada to determine evapotranspiration by greasewood, rabbitbrush (Chrysothamus spp.), willow, and wildrose (Rosa spp.) (Robinson 1970). The tanks, similar in design to those installed at Buckeye, Arizona (study 2 above), and described by Robinson and Bowser (1959), were operated during the growing season, April 1 to October 20, from 1961 through 1967. Evapotranspiration by the plants was computed as the sum of rainfall, soil moisture depletion, and water supplied to the tanks during the growing season. Plant growth, development, and water use were adversely affected during some years as a result of damage to the plants by rabbits, insects, and boron toxicity.

Annual water use by greasewood ranged from 1.21 to 1.81 acre-feet per acre with depths to the water table of 5.0 to 7.8 feet. About 50 to 55 per cent of the water used was supplied by ground water. The average annual evapotranspiration rate by rabbitbrush was 1.66 acre-feet per acre, of which 64 per cent was supplied by ground water. The evapotranspiration rate of willow was the highest of the

four species, amounting to 3.03 acre-feet per acre annually. Willow was also the highest user of ground water, obtaining 82 per cent of its water from that source. Evapotranspiration by wildrose averaged 1.48 acre-feet per acre with a depth to water of five to six feet and 1.71 acre-feet per acre with depths to ground water ranging from 4.2 to 5.0 feet. On the average, ground water supplied 70 per cent of the total use, and soil moisture only ten per cent. Evaporation from a bare-soil surface was less than half the evapotranspiration losses of the phreatophytic vegetation. It ranged from 0.36 when the water table depth was 4 feet, to one-acre-foot per acre with the water table at 1.9 feet.

The climatic conditions in Winnemucca, Nevada, where this study took place, are different (cooler temperatures, lower pan evaporation, and shorter growing season) from those in most parts of Arizona and any attempt to extrapolate the data directly to portions of Arizona could result in errors.

Study No. 5:

Measurements were made of water used by three native meadow grasses (saltgrass [Distichlis stricta Torr.], sedges [Carex spp.], and bluejoint [Elymus tritcoides Buckl.]) growing in evapotranspiration tanks at Winnemucca, Nevada in 1967, 1968, and 1969 (Dylla, Stuart, and Michener 1972). In addition, water use measurements were made on two domestic

forage species, tall wheatgrass (Agropyron rigidum Beauv.) and Alta fescue (Festuca arundinacea Schreb.), in 1968 and 1969. Saltgrass and sedges were grown with a seasonal high water table (wet meadow); and bluejoint, tall wheatgrass, and Alta fescue were grown with a seasonal high water table and surface irrigation treatments.

Sedges grown under wet meadow conditions used an average of 25.1 inches of water during a growing season lasting from May to October. In comparison, saltgrass used an average of 20.3 inches of water per season. Bluejoint used an average of 23.5 inches. Under wet meadow conditions, tall wheatgrass used 27.8 and 23.6 inches of water in 1968 and 1969, and Alta fescue used 25.7 and 19.4 inches, respectively. Grown under surface-irrigated conditions, bluejoint used 34.6 and 32.1 inches of water in 1968 and 1969, as compared to 32.2 and 29.5 inches for tall wheatgrass and 29.9 and 26.4 for Alta fescue, respectively.

Study No. 6:

An extensive evapotranspirometer study has been conducted on the Rio Grande River floodplain in Bernardo, New Mexico since 1962. Evapotranspiration by tamarisk, saltgrass, and more recently Russian olive is being investigated, as well as evaporation from bare soil of various textures utilizing 30 tanks. Nine tanks have a surface area of 1,000 square feet and a depth of 12 feet. The rest are

constructed of 55 gallon drums with a surface area of 2.7 square feet and are used for the bare soil and saltgrass studies. The tanks were flushed yearly by forcing fresh water through the stand pipe and the laterals at the bottom of the tank. Thus, water was driven from the bottom of the tanks to the top and prevented the accumulation of salt in the ground water.

Preliminary results were reported for tamarisk by Lowry (1966), and a summary of all data to 1971 was obtained from the Albuquerque Development Office, USDI Bureau of Reclamation. The summary data indicate that saltcedar used approximately 3.4, 2.9, and 3.8 feet of water annually with depths to water of six, three, and five feet, respectively. The tanks with water tables at three feet generally showed a consistent reduction from tanks with water table depths of five feet or more not only in water loss, but also in the development of a vegetation cover (Horton and Campbell 1974). Annual water use declined when sodium chloride was added to the water supply in two of the saltcedar tanks.

When the water table was dropped rapidly from a depth of 5.6 feet to a depth of nine feet by pumping water out of the tanks, evapotranspiration by saltcedar plants was reduced to almost half its original rate. However, in the following year, tamarisk was using nearly as much water at a depth of nine feet as it had at the original depth of 5.6 feet; presumably because the root system adapted to the

deeper ground water situation. Saltgrass grown in the tanks with water table depths of two feet used two feet of water annually, and only 1.5 feet when covered by 50 per cent shade. Evaporation from bare soil was greater for shallow water tables than from deeper water tables.

According to Horton and Campbell (1974), the Bernardo tanks seem to demonstrate that shallow water-table depths are not optimum for tamarisk, and that when the root system is developed, the water loss from deeper water tables may be similar to losses from more shallow ground water depths if the ground water is not saline. Using small tanks (two feet in diameter and six feet deep) near the Santa Ana River at Santa Ana, California, Blaney (1933) found that annual water use by saltgrass in acre-feet per acre ranged from 3.5 to 1.1 for depths to water of one to five feet, respectively. In this same area, bermuda grass used 3.1 and 2.6 acre-feet per acre of water annually for depths to water of two and three feet, respectively. Near Owens River, California, Lee (1912) reported similar results of water use by saltgrass grown in tanks. Annual water use in acre-feet per acre ranged from 4.05 to 1.2 for depths to water of 1.45 to 4.94 feet, respectively.

Direct comparison of water use by grass and tamarisk grown in tanks is difficult, according to Horton and Campbell (1974). Shallow water-table depths are maintained for purposes of comparing water use between grass and

saltcedar. Therefore, the water loss includes a large percentage of evaporation from the soil which may not occur under more natural conditions. Saltcedar does not mature into a vigorous stand where the water is close to the surface. On the other hand, grass does not develop at water tables optimum for saltcedar growth because the water table is too deep for the grass.

The information gained from tank studies has been used to estimate water savings along cleared river reaches. Turner and Skibitzke (1952) estimated that clearing a 2,000 foot channel along the Salt and Gila Rivers for a distance of 70 miles would save about 0.8 acre-feet of water per acre per year. This estimate did not include allowance for transpiration from replacement vegetation. Blaney (1961), using tank data, estimated that by replacing saltcedar with bermuda grass on 30,310 acres along the Pecos River in New Mexico, 66,195 acre-feet of water could be saved annually, a salvage of 48 per cent or approximately 2.3 acre-feet per acre per year.

Unfortunately, none of these estimates of water use by various phreatophyte species growing in tanks can be verified. The tank method for determining evapotranspiration of riparian plant species is a time consuming (study periods have ranged from one year to ten years) and expensive process. Water use data obtained from tank studies is only accurate for periods of one month or longer

because of inconsistencies in day to day water use measurements. Finally, when water use data obtained from tank studies are extrapolated to natural riparian areas, large errors are possible because the tank environment cannot simulate all of the physical variables of a natural riparian environment.

Evapotranspiration Tent Studies. The evapotranspiration tent technique developed by Decker, Gaylor, and Cole (1962) has been used to investigate water losses of both saltcedar and bermuda grass. The method requires that a plant be enclosed within a tent. The absolute humidity difference between the inlet and outlet is multiplied by the ventilation rate and cross-sectional area of the outlet to give an estimate of the evapotranspiration rate of the enclosed plots. This method measures the evapotranspiration of plants in their natural state. However, only a limited sample of the vegetation can actually be measured at any one time. The tent creates enclosure effects such as forced air movement and heat pockets which alter the evapotranspiration rates of the enclosed plants (Lee 1966).

Study No. 1:

An investigation of the evapotranspiration rates from tamarisk by the tent technique was conducted by Mace (1968) on the Gila River floodplain on the San Carlos Indian Reservation. Measurements were made on three areas with

depths to ground water of 3, 14, and 20 feet. Results of the study indicate that the evapotranspiration rates of tamarisk were lowest during February, March, and April (periods of defoliation). Measurements during July and August revealed that the greatest loss of approximately 12.5 inches per month occurred on the area with a depth to ground water of three feet. The other areas with depths to water of 14 and 20 feet had water losses of approximately seven and ten inches per month, respectively, during July and August. Higher soil and ground water salinity in the areas with a 14-foot deep water table than in the area with a 20-foot deep water table, may have caused tamarisk to transpire less than in the area with a 20-foot deep water table.

Study No. 2:

During July and August of 1958, evapotranspiration measurements by the tent technique were made on paired plots (one of closely grazed bermuda grass sod, the other of sod overtopped by one or more tamarisk shrubs) in an old bed of the Salt River by Decker (1960). The plot with the most tamarisk was only about one-third fully stocked, and its evapotranspiration rate was about four times that of the adjacent grass plot. The water table was two to ten inches below the surface.

Study No. 3:

Transpiration by tamarisk shrubs occupying a narrow floodplain between the San Pedro and Gila Rivers near Winkleman, Arizona, was measured by the tent technique during the summer in 1966 (Sebenik and Thames 1967). Two replicate runs of four hours each were made on five days between July 15 and September 9. The water table was eight to nine feet below the surface when the measurements were made. The results of the study indicate that an average monthly loss of 1.1 acre-feet from July to September occurred in this area of tamarisk growth.

Studies Based on Water Table Fluctuations. Interpretation of the diurnal fluctuations of the water table as a method for determining evapotranspiration was first proposed by Smith in 1922 (cited by White 1932). Evapotranspiration is estimated by the equation:

$$d = Sy\ (24r \pm S)$$

where d is the depth of water loss, Sy is the specific yield of the porous medium, r is the hourly rate of rise in water table elevation from midnight to 4 a.m., and S is the change in water table elevation (rise or fall) during a 24-hour period. Advantages of this method are that measurements of water use can be made on vegetation growing in its native habitat and on undisturbed soil. However, the average specific yield of a large non-uniform soil mass underlying

a given area is difficult to determine (Muckel 1966). This method assumes that water is withdrawn by evapotranspiration uniformly over an area containing phreatophyte species and that the well site is an unbiased sample of a larger area. According to Horton and Campbell (1974), many studies have had insufficient wells to give a good statistical indication of changes in water use, and thus have been criticized because the conclusions were reached with too few wells. Gary and Campbell (1965) suggested that the withdrawal of water from the capillary fringe or water table is "undoubtedly" not uniform on floodplains containing mixed riparian species of differing age. Furthermore, the method is not valid (1) when the water level in the well is affected by pumping, (2) if the stage is changing in a nearby body of water, or (3) when the ground water fluctuations are affected by rainfall (Robinson 1966).

White (1932) used this method in Escalante Valley near Milford, Utah, and reported that saltgrass and greasewood used an estimated 1.24 acre-feet per acre of water during the growing season. Shadscale and greasewood used 0.38 and 0.22 acre-feet per acre of water during the growing season, respectively. Gary (1962) and Gary and Campbell (1965) observed decreased water table fluctuations after the removal of tamarisk on the Salt River floodplain, but were unable to determine evapotranspiration rates.

Qashu and Evans (1967) investigated the quantity of water removed annually by evapotranspiration and subsurface seepage along Walnut Gulch, an ephemeral stream near Tombstone, Arizona, using both the diurnal changes in water table elevations and a water balance method. Total annual water use by mesquite along the channel reach was estimated to be 4.3 acre-feet per acre.

In the same area (Walnut Gulch), Tromble (1972) estimated water use by mesquite on an alluvial pocket aquifer which performed as a lysimeter. Water use was determined by measuring fluctuations in the ground water table. Amount of water lost during the winter season was assumed to be due to subsurface seepage; the same amount was subtracted from growing season water use to give an estimate of actual evapotranspiration. Daily evapotranspiration rates for the first half of June were calculated to be 1.07 cm/day.

Model Studies. Hughes (1971) developed a model based on an empirical mass transfer equation to determine the conditions under which removal of saltcedar plants might yield a net increase in water supply. The model simulates the amount of water evaporated into the atmosphere without the plants (primarily evaporation from soil), and utilizes air temperature, humidity, wind speed, plant density, and water table depth as variables. The model was developed

using data obtained from the Bernardo Tank studies conducted in New Mexico.

Saltcedar plants having a high rate of transpiration over a wide area tend to increase humidity and reduce temperature in the area covered by the plants (Hughes 1971). In addition, a large body of plants tended to reduce air movement close to the ground surface (Hughes 1971). When removed, the resulting increase in temperature and air movement and decrease in humidity may cause increased local evaporation from the soil. The model was designed to take these factors into account.

This study suggested that under most conditions, additional water would be obtained in the Middle Rio Grande Valley through the removal of saltcedar plants. As much as 2.5 acre-feet per acre of water may be salvaged under optimum conditions. However, the estimated quantity of water salvaged varied as to the volume density of the saltcedar and also with the depth to groundwater prior to plant removal. In some situations, there was no estimated increase in water yield following removal of saltcedar.

Climatological Methods. Empirical formulas have been developed for expressing relationships between evapotranspiration rates and climatic factors. In some cases coefficients for particular plant species are included. The formulas are based on the following principle pointed

out by Thornthwaite (1948): when the root zone of the soil is well supplied with water, the amount used by the vegetation depends more on the amount of solar energy received by the surface and the resultant air temperature than on the kind of vegetation growing in the area.

The Blaney-Criddle formula is frequently used for estimating evapotranspiration of riparian vegetation in the arid Southwest where it was developed. Actual measurements of water use under each of the physical and climatic conditions of any large area are expensive and time consuming. The Blaney-Criddle formula offers a rapid means for attempting to transfer the results of measurements from one area to another with apparently similar vegetative and climatic conditions. Measured use of water by months is related to mean monthly temperature and percentage of daytime hours to develop a consumptive use coefficient. An empirical coefficient for the particular species and cover is also developed. These coefficients are applied to mean monthly temperature and number of daytime hours for other areas to obtain estimates of consumptive use.

To compensate for different growth conditions, Blaney and Criddle (1962) developed vegetation coefficients for qualitative expressions of cover. Rantz (1968) proposed a graphical method for estimating a coefficient for different depths to water.

Data on annual or seasonal consumptive use of ground water by phreatophytes in the Southwest computed by the Blaney-Criddle formula are given by Blaney (1961). Shakur (1964) compared evapotranspiration rates of saltcedar measured with tanks at Buckeye, Arizona with computed Blaney-Criddle values for September and October of 1962. For September, computed evapotranspiration was .60 cm/day compared to a measured figure of 0.58 cm/day. For October, evapotranspiration was computed to be 0.41 cm/day and the measured rate was 0.43 cm/day.

Thornwaite's (1948) formula has no consumptive use factor, but includes the variables of air temperature and daylength. Shakur (1964) found that the results obtained by the Thornthwaite method for evapotranspiration of saltcedar were within 94 per cent of the measured tank results at Buckeye, Arizona. This method is not suited for calculating evapotranspiration by phreatophyte stands in the West because of the requirement that the stands be surrounded by an unlimited area of actively transpiring vegetation adequately supplied with water (Robinson 1966).

Aerodynamic and Energy Budget Methods. The aerodynamic and energy budget methods (Sellers 1967) have been tested at the Buckeye Project using results from evapotranspirometers as a control. According to van Hylckama (1960), if either the aerodynamic or energy budget methods

would successfully measure transpiration rates of saltcedar, the necessary instruments could be moved to water-use problem sites to quickly obtain results. Instead it has been necessary to resort to the time-and-money consuming method of the water budget with results only applicable to the local area of the test site.

The results of aerodynamic and energy budget tests at the Buckeye Project have not been published by van Hylckama; however, partial findings have been reported by Shakur (1964). For September and October, evapotranspiration by saltcedar computed by the Thornthwaite-Holzman equation in the adiabatic form was 1.2 times the measured evapotranspiration. The inaccurate results were attributed to incorrect measurements and an inappropriate location of instruments, not to the method itself. Evapotranspiration rates as determined by the Bowen ratio approach (an energy budget method) during the same time period were three per cent less than the measured evapotranspiration rates. The energy budget method gave more consistent results than the aerodynamic approach. It was concluded that the instrumentation developed for measuring and recording factors needed in aerodynamic and energy budget approaches was not reliable and practical. The average data yield during the period of analysis was only about 40 per cent, a low percentage.

Summary of Water Use Studies. Table 5 summarizes the results of riparian vegetation water use studies conducted in the Southwest which were discussed previously. The water budget and paired watershed methods are generally designed to measure changes in water use following particular treatments to increase water yields from an area. However, these two methods may also indicate water use by vegetation just as the tank and evapotranspiration tent methods do. Therefore, they are included in Table 5.

When all of the data from the above studies are considered, a trend in the water use between species is apparent. Saltcedar, arrowweed, cottonwood, and hydrophytes (tules and cattails) are the heaviest users of water (annual use of between four and eight feet of water). The intermediate users of water are seepwillow, mesquite, quailbrush, four-wing saltbush, and greasewood (annual use of between two and five feet of water). The least amount of water is transpired by grasses such as salt grass, bermuda grass, sedges and from bare soils (annual use of less than three feet of water).

Conditions in the area to be treated, such as depth to ground water, salinity of ground water, stage of plant growth, and climatic conditions, may help determine the amount of water which potentially can be salvaged. Areas with depths to ground water of 4 to 20 feet, low soil and water salinity, and young, vigorous stands of the heavier

Table 5. Summary of riparian vegetation water used in the southwest as determined by tank, evapotranspiration tent, water table fluctuation, water budget, and paired watershed methods.

Locality or River System	Mean Annual Temperature (°F)	Mean Annual Precipitation (Inches)	Ave. Growing Season (Days)	Years of Work	Tank or Treated Area Size	Vegetation	Annual Water Use (Feet)	Depth to Water (Feet)	Remarks	Authority
Tank Studies:										
Gila River, Lower Safford Valley, Arizona	63	9.0	200	1	circular 4.6 & 10 ft. in diam. 3.5-10 ft. deep	saltcedar cottonwood seepwillow mesquite	7.2 6.0 4.7 3.3	4 to 7 6 2 to 6 --	Set in ground in native vegetation	Gatewood et al. (1950)
Gila River, Buckeye, Arizona	69	7.5	300	10	square 33 x 33 ft. 12 ft. deep	saltcedar saltcedar saltcedar	8.0 4.6 3.3	5 7 9	Preliminary results from first 2 years of study	van Hylckama (1963)
Lower Colorado River, Yuma, Arizona	72	3.4	327	4	square 32 x 32 ft. 5-7 ft. deep	arrowweed quailbrush saltbush bare soil bare soil cattail	8.7 3.0 2.4 1.75 0.6 8.6	5.6 5.5 5.5 2.0 3.0	Set in ground in native vegetation Roots submerged	Hughes & McDonald (1966)
Rio Grande River, Bernardo, New Mexico	53	6.1	140	10		saltcedar saltcedar saltcedar	3.4 2.9 3.8	5-7.5 3.0 5.0	Set in ground in native vegetation	Lowry (1966)
Humbolt River Valley, Winnemucca, Nevada	47.4	8.6	140	5	square 30 x 30 ft. 10.5 ft. deep	greasewood greasewood greasewood greasewood rabbit-brush willow wildrose bare soil bare soil	1.8 1.2 1.2 1.4 1.9 3.0 1.5 1.0 0.36	5.0 6.0 7.5 8.0 5.0 5.0 5-6 1.9 4.0	Some damage to plants by rabbits and boron toxicity during part of study	Robinson (1970)

Table 5.--Continued Summary of riparian vegetation water used in the southwest as determined by tank, evapotranspiration tent, water table fluctuation, water budget, and paired watershed methods.

Locality or River System	Mean Annual Temperature (°F)	Mean Annual Precipitation (Inches)	Ave. Growing Season (Days)	Years of Work	Tank or Treated Area Size	Vegetation	Annual Water Use (Feet)	Depth to Water (Feet)	Remarks	Authority
Santa Ana River, Santa Ana, California	61.7	12.3	304	1-1/2 2-1/2 1 1-1/2 1-1/3	circular 2 x 6 feet	saltgrass saltgrass saltgrass saltgrass saltgrass	3.5 3.0 2.1 1.1 1.6	1.0 2.0 3.0 4.0 5.0	Set in ground in native vegetation	Blaney (1933)
Santa Ana River, San Bernardino, California	62.9	16.0	252	2 2-1/2 2	circular 2 x 3 feet	bermuda bermuda tules	3.1 2.6 5.2	2.0 3.0	 Roots submerged	Blaney (1933)
Santa Ana River, Santa Ana, California	61.7	12.3	304	2 2 1-1/2	circular 6 x 3 feet	tules cattails willow	5.3 5.3 4.0	 2.0	Roots submerged Set in ground in native vegetation	Blaney (1933)
Mohave River, Victorville, California	63.5	5.4	255	2	circular 6 x 3 feet 2 x 6 feet	tules tules	6.5 7.0		Roots submerged	Blaney (1933)
Owens River, Independence Region, California	57.6	5.3	197	2	circular 7.4 x 5.5 feet	saltgrass saltgrass saltgrass saltgrass saltgrass saltgrass	4.05 3.73 3.35 2.05 2.64 1.12	1.45 1.86 2.90 3.81 4.46 4.94		Lee (1912)
Middle Rio Grande Valley, Los Griegos, New Mexico	55.6	8.5	196	2 2 2	circular 4 x 4 feet 4 x 3 feet 4 x 2 feet	saltgrass saltgrass saltgrass	1.70 2.85 3.95	2.10 1.25 0.42		Cited by Lee (1942)

Table 5.--Continued Summary of riparian vegetation water used in the southwest as determined by tank, evapotranspiration tent, water table fluctuation, water budget, and paired watershed methods.

Locality or River System	Mean Annual Temperature (°F)	Mean Annual Precipitation (Inches)	Ave. Growing Season (Days)	Years of Work	Tank or Treated Area Size	Vegetation	Annual Water Use (Feet)	Depth to Water (Feet)	Remarks	Authority
Humbolt River Valley, Winnemucca, Nevada	47.4	8.6	140	3	circular 5 x 6.5 ft.	sedges	2.3		1967 grown	Dylla et al. (1972)
						sedges	2.2		1968 under wet	
						sedges	1.8		1969 meadow comditions	
						saltgrass	1.8		1967	
						saltgrass	1.6		1968	
						saltgrass	1.6		1969	
						bluejoint	2.0		1967	
						bluejoint	1.9		1968	
						bluejoint	1.8		1969	
						tall wheatgrass	2.3		1968	
						tall wheatgrass	2.0		1969	
						alta fescue	2.1		1968	
						alta fescue	1.6		1969	
Evapotranspiration Tent Technique:							(ll/Mo.)			
Gila River, San Carlos Indian Reservation, Arizona	65.9	13.8	265	5 mo,	Tent	saltcedar	12.5	3.0	July-Aug.	Mace (1968)
						saltcedar	7.0	14.0	July-Aug.	
						saltcedar	10.1	20.0	July-Aug.	
San Pedro and Gila Rivers, Winkleman, Arizona	65.9	10.8	179	3 mo.	Tent	saltcedar	1.1 (Acre ft./mo.)	9.0	July-Sept.	Sebenik & Thames (1967)
Water Table Method Diurnal Fluctuation:										
Escalante Valley, Milford, Utah		9.2	150	2		alfalfa	2.26		computed from automatic water-stage records and specific yield by formula q=y (24r ± s) for growing season only	White (1932)
						saltgrass-greasewood	1.24			
						shadscale	.32			
						greasewood	.22			

Table 5.--Continued Summary of riparian vegetation water used in the southwest as determined by tank, evapotranspiration tent, water table fluctuations, water budget, and paired watershed methods.

Locality or River System	Mean Annual Temperature (°F)	Mean Annual Precipitation (Inches)	Ave. Growing Season (Days)	Years of Work	Tank or Treated Area Size	Vegetation	Annual Water Use (Feet)	Depth to Water (Feet)	Remarks	Authority
Water Budget Method:							(Acre ft./day)			
Gila River, San Carlos Indian Reservation, Arizona	65.9	13,8	265	10	1,720 acres	saltcedar & mesquite	21 13		Before clearing After clearing Preliminary results	Culler (1970)
Walnut Gulch, Tombstone, Arizona	63.1	14,1	229	1		mesquite	4.3		Loss from channel reach	Qashu & Evans (1967)
Cottonwood Wash, Mohave County, Arizona						cottonwood, willow, ash & seep-willow	80 42 (Acre ft./ growing season)		Before clearing After clearing	Bowie & Kam (1968)
Paired Watershed Treatments:										
Hassayampa River near Prescott, Arizona	52.8	24.0	147	11		chaparral			Flow increased .63 and .97 area inches in 1968 and 1969 respectively after chemical treatment	Ingebo (1971)

Table 5.--Continued Summary of riparian vegetation water used in the southwest as determined by tank, evapotranspiration tent, water table fluctuations, water budget, and paired watershed methods.

Locality or River System	Mean Annual Temperature (°F)	Mean Annual Precipitation (Inches)	Ave. Growing Season (Days)	Years of Work	Tank or Treated Area Size	Vegetation	Annual Water Use (Feet)	Depth to Water (Feet)	Remarks	Authority
Monroe canyon, San Dimas Experimental Forest, Southern California		25.5		2	38 acres treated	alder, maple, willow, sycamore, & mixed oak woodland			After treatment flow increased 17.4 acre ft. during first drying season, 12.8 acre-ft. during 1st rain season, & 14 AF second drying season	Rowe (1963)
Workman Creek, Sierra Ancha Experimental Forest, Arizona	59.9	32.0	179	5	.6% of total basal area on 248 acres was cut	Arizona alder & bigtooth maple			No measurable increase in flow after treatment	Rich, Reynolds, & West (1961)

water-using species may yield the greatest water gains following treatment. On the other hand, areas with either shallow or deep water tables, high soil and water salinity, and comparatively mature and scattered species of intermediate water using capacity may indicate conditions with less potential for water salvage by means of vegetation management practices.

Chemical Clearing Treatment Results

Research to determine effective means for controlling saltcedar with herbicides has been primarily concerned with types, rates and timing of herbicide applications.

Basal and Stump Herbicide Applications. Basal and stump applications of ester and oil-soluble amino formulations of 2, 4, and 5-trichlorophenosypropionic acid (silvex) were effective for control of saltcedar in New Mexico, according to Hughes (1965). Trees with trunk diameters larger than two inches were more difficult to kill than smaller trees and retreatment was often needed. Cutting the larger trees and spraying the stumps increased the effectiveness of herbicide applications.

Soil Surface Applied Herbicides. Studies of six granular herbicides for control of saltcedar applied at five and 20/lb acre by Hughes (1966) indicated that 2 methoxy-3, 6-dichlorobenzoic acid (dicamba) gave better than 50 per cent

control even at the lower rate. Another herbicide, 4-amino-3, 5, 6-tri-chloropicolinic acid (picloram) was moderately effective at the higher rate. Soil-spray herbicides were less effective, with only one herbicide, 3-(3, 4-diclorophenyl)-1, -1-dimethylurea (diuron) producing measurable results after 16 months.

Dicamba granules were aerially applied at rates of ten and 20 lb/acre to a sandy site on the Bitterlakes Wildlife Refuge near Roswell, New Mexico and on the delta of McMillan Reservoir which has a finer-textured soil than that at Roswell (Hughes 1967). Preliminary results indicated that both rates were effective on the sandy site, but there was no visible effect from the treatment on the fine-textured soil. High clay content of the surface soil on McMillan delta may have prevented movement of the herbicide to the roots of saltcedar. One-half of the saltcedar growing on the sandy site was crushed with the Le Tourneau Tree Crusher prior to treatment. This area showed little effect from the dicamba, perhaps because the crushing operation delayed plant growth until after rainfall had leached the herbicide past the root zone.

Hollingsworth (1973) concluded that herbicide granules or spray applied to the soil surface were ineffective for saltcedar control in the Southwest.

Foliage Applied Herbicide Sprays. Arle (1960) compared the effects of silvex with 2, 4-dicholorophenoxyacetic acid (2, 4-D), 2,4, 5-trichlorophenoxyacetic acid (2,4, 5-T), and with mixtures of 2, 4-D and 2,4, 5-T on saltcedar following mechanical clearing and burning. Chemicals were applied to the foliage at rates of 3,4, and 5 lb/acre on six-month old regrowth and repeated three times at six-month intervals. None of the materials caused a high percentage of eradication following the initial treatment. However, repeated treatments resulted in a comparatively high degree of plant kill, with silvex being more effective than the other chemicals after each treatment. The lowest rate of application in the experiment resulted in good control when repeated three times. This study indicated that repeated treatments are required for effective control of saltcedar.

When unmowed saltcedar was sprayed in May with two lb/acre in August of the same year, the density of the stand was reduced by approximately 50 per cent compared to a 16 per cent reduction in density for a stand treated with one application of four lb/acre of silvex in May at a New Mexico site (Hughes 1966). When stands were moved in March, sprayed with two lb/acre of silvex in May, and again in July of 1966, the density of saltcedar stands was reduced by as much as 100 per cent (Hughes 1967). Saltcedar root samples were collected weekly from plots which had been mowed in August and September of 1966 as well as unmowed

plots. Carbohydrate analysis of these samples showed that saltcedar plants which had been mowed the previous August had root carbohydrate levels that were 37 per cent lower than unmowed plants. Lower root carbohydrate levels probably contributed to the better results obtained by spraying mowed plants as opposed to unmowed plants.

Field and greenhouse experiments conducted by Messinger (1970) showed that mixtures of silvex and picloram are synergistic when utilized on saltcedar. Field trials revealed that oil is superior to water as a carrier for chemicals, and that immature saltcedar was easier to control than mature saltcedar.

Weather conditions in the southwestern United States, i.e., high air temperatures and radiation levels and low humidity, tend to cause rapid evaporation of herbicide spray solutions on saltcedar leaves and may be one of the factors making saltcedar difficult to control. Hughes (1968) conducted greenhouse studies to determine the effects of adding hygroscopic compounds to phenoxy herbicides for control of saltcedar. Hygroscopic compounds keep the herbicide in an aqueous state for a longer period of time, thus allowing more herbicide to enter the plant than if the hygroscopic compounds were not used. Injury to foliage from all herbicides tested increased when the hygroscopic compound, polypropylenediol, was added to the spray solution at five per cent concentration by volume.

The increased activity was affected by the amount of polypropylenediol added, air temperature, relative humidity, and herbicide formulation.

Dormant Applied Herbicide Sprays. Herbicides have been applied to dormant phreatophytes to avoid damage to crops which are cultivated near the stands during the growing season. Although the application rates are high and more expensive than other treatments, they have been effective. Hughes (1967) reported that six lb/acre of silvex ester in 50 GPA of diesel oil applied in January while saltcedar plants were dormant, following an August mowing, resulted in an 85 per cent kill.

Quimby (1968) reported that an aerial-applied dormant treatment of 4, 6, and 8 lb/acre of silvex ester in 20 GPA of diesel oil caused the density of saltcedar stands to be reduced by 48, 60, and 74 per cent, respectively.

The response of saltcedar to herbicidal spray on the stem and leaves has varied, with no satisfactory control achieved except following several years of repeated treatment (Hollingsworth 1973). Seedling plants up to two years in age are probably the most susceptible to treatment, followed by first-year regrowth on older crowns. Once saltcedar shoots develop a cutinized outer bark layer and stem buds, their resistance to herbicide sprays is increased. If the plants are several years old, it is

necessary to mow, crush, or otherwise destroy the top, and then spray the crown regrowth to obtain satisfactory control. According to Hollingsworth (1973), vegetative propagation and regrowth are probably the prime factors which allow saltcedar plants to survive control efforts. There are numerous buds along the stems and branches of the plant and covering the crown. Only a few buds initiate growth in a given year with the remainder being dormant. When the plant is defoliated by a herbicide treatment, previously dormant buds are stimulated to grow. If successive herbicide treatments kill all of the plant above ground, then dormant buds on the root crown are activated and produce new shoots.

Chem-cut and Chem-plow Herbicide Application. The chem-cut procedure combines mechanical clearing and chemical application into one operation in which herbicide is applied at the same time the brush is being cut by a rotary mower. During 1968, approximately 1,670 acres of phreatophytes near the Caballo Reservoir, New Mexico, were controlled by the use of the chem-cut machine, using mixtures of TA-120 (2,4, 5-T) and 2,4, 5-TP (Schachterle 1969b, 1969c).

The USDA Agricultural Research Service determined that herbicides were readily translocated acropetally (proceeding from the base to the apex) to the shoots of saltcedar in the transpiration stream after application to the root zone (Quimby 1970). Also, C-14 labeled 2, 4-D and

dicamba were found to be basipetally (proceeding from the apex to the base) translocated in herbaceous, immature stems, but not in woody stems of saltcedar. These results were based on laboratory and greenhouse studies and led to development of the chem-plow. With this machine, roots are severed and herbicide is delivered to the severed zone simultaneously. Tables 6 and 7 show the response of saltcedar and grasses following chem-plow treatment. The phenoxy herbicides and picloram were least damaging to the grass species present. Deep placement of selective herbicides plus a minimum of soil disturbance with this method improves chances of survival and establishment of grasses compared to other treatment techniques (Hollingsworth 1970).

Where the terrain will permit use, the injection of herbicides by root plow for control of saltcedar may be comparatively effective. The greatest disadvantage of the root plow is its high cost compared to other control techniques (Hollingsworth 1973). However, if large saltcedar plants have to be crushed, chopped, or mowed to obtain regrowth which is more susceptible to spray treatments, and then sprayed for several years, the total cost may exceed that for the root plow injection treatment.

In general, basal and stump, soil surface, foliage, and herbicides applied when plants are dormant have not provided satisfactory control of saltcedar except under a few conditions, or following several years of repeated

Table 6. The response of saltcedar to herbicides applied in a 40-inch wide band 12-16 inches below the soil surface with a root plow which also severed the root system (Hollingsworth 1970).

Herbicide	Rate lb/ac	Per Cent[a] Control	Grass[b] Vigor
2,4, 5-TP (K-salt)	15	93	6
Tordon 212 (Picloram)	9	98	8
Fenuron	12	50	0
Monuron	12	78	0
Diuron	12	90	0
Dicamba	10	93	6
2,4-D Amine plus	10	94	8
2,4-D ester	10		
Plowed only	--	15	8

[a]The control figures, obtained five months after treatment pertain to the 48-inch wide treated area, and not the unplowed strips between treatments.

[b]Native saltgrass 0-10 rating with 0 = all dead and 10 = no effect.

Table 7. The response of saltcedar to herbicides applied in an 8-foot wide band 18-24 inches below the soil surface with a root plow which also severed the root system (Hollingsworth 1970).

Herbicide	Rate lb/ac	Per Cent[a] Control	Observations
2,4-D Amine	8	80	60% grass kill. 40% of uncut plants showing leaf tip injury.
Tordon 155 (Picloram)	4	75	50% grass kill. Some leaf tip injury to uncut plants.
Dicamba	8	90	All grass dead. Plants in uncut strip showing dicamba symptoms.
Monuron	5	90	All grass dead. Obvious herbicide response in uncut plants.
Diuron	5	90	All grass dead. Obvious herbicide response in uncut plants.

[a]The control figures, obtained 16 months after treatment, pertain to the treated band, and not to the unplowed strips between treatments.

treatment. Vegetative propagation and regrowth from dormant buds in the stems and crown, a cutinized outer bark layer resistant to herbicide sprays, and no basipetal translocation of herbicides in woody stems, have prevented successful control with chemicals in most instances. The chem-plow appears to have overcome these obstacles, although at a higher cost than the previously discussed methods.

Hydrologic Response to Water Yield Improvement

Only one major study in Arizona was designed to evaluate the hydrologic response following eradication of phreatophyte vegetation on relatively low level floodplains. This study is described below under water budget studies. Results of several riparian clearing projects conducted on higher elevation perennial streams are also presented in this section involving both water budget and paired watershed research methodologies.

Water Budget Studies

When the water budget is adapted to a reach of a stream valley, evapotranspiration rates are calculated as the difference or residual between surface and subsurface water entering and leaving the reach, plus or minus soil moisture change, plus precipitation. The reliability of the method depends on the accuracy with which inflow and outflow variables can be measured or estimated.

The Gila River Phreatophyte Project was begun in 1962 by the USDI Geological Survey to determine actual evapotranspiration rates of phreatophytes by the water budget method. The project area consists of three consecutive five-mile long subreaches along the Gila River on the San Carlos Apache Indian Reservation. Extensive instrumentation needed to obtain measurements for the water budget included four stream gaging stations on the Gila River, 62 stream gaging stations on tributaries, 72 wells to record water level fluctuations, 72 access tubes to measure soil moisture with the neutron probe, and 24 raingages for precipitation measurement. Culler (1970) reported some partial results after mechanically clearing 1,720 acres of tamarisk and mesquite on one of the study subreaches. He compared water budgets for a six-month period (February-July) before and after treatment. Average evapotranspiration, which was 21 acre-feet per day before treatment, declined to 13 acre-feet per day after treatment, representing an estimated water savings of eight acre-feet per day or an average of 0.8 acre-feet per acre for the six-month period. According to Culler (1970), actual salvage of water probably would decline as replacement vegetation became established. Horton (1972) reported that only 45 per cent of the area was under phreatophyte canopy; the remainder was open vegetation. Thus, according to Horton (1972) if the amount were credited to the area of dense

cover actually cleared, the savings would possibly be 1.8 acre-feet per acre of phreatophyte vegetation cleared.

More recently, Hanson, Kipple, and Culler (1972) reported that a water budget analysis for this same area indicated a reduction in the average consumptive use from 50 inches per year before clearing to 20 inches per year after clearing. Before clearing, the phreatophyte cover consisted primarily of saltcedar with an aerial density ranging between 39 and 80 per cent canopy cover. After treatment, the cover consisted primarily of bare ground and no estimates of water use by replacement grass or crops were obtained in the analysis.

Change in water use as a result of the eradication of riparian vegetation in Cottonwood Wash, Mohave County, Arizona, was determined by Bowie and Kam (1968) using the water budget method. A 4.1-mile length of the stream channel was divided into a 2.6-mile upper reach and a 1.5-mile lower reach. Measurements of streamflow, ground water levels, vegetation, and meteorological phenomena in the area were obtained to estimate use of water by riparian vegetation under natural hydrologic conditions. The primary species were Fremont cottonwood, red willow, velvet ash, and seep willow.

Change in water use as a result of chemical defoliation and eradication of the vegetation in the lower reach was subsequently determined. The average loss of water,

which was 80 acre-feet per growing season before treatment, declined to 42 acre-feet per growing season after treatment, providing an estimated salvage of 38 acre-feet of water per growing season for the lower 1.5-mile reach.

Evaluation of transpiration-well data (water table fluctuation method) indicated that the eradication of vegetation may reduce the calculated water use near the transpiration well by 90 per cent (Bowie and Kam 1968). Eradication reduced shading of soil and water surfaces, and possibly allowed an increase in wind speed at ground level causing a higher rate of evaporation from the soil. Therefore, the decrease in water use as computed is not a measure of transpiration alone but also includes a probable increase in evaporation according to Bowie and Kam (1968).

During a five-year period Thomsen and Schumann (1968) conducted a water-budget study on the lower ten miles of Sycamore Creek in Maricopa County, Arizona. Riparian vegetation covered approximately 1400 acres in the channel and on the floodplain. Vegetation was dense on the lower half where the depth to water was generally less than 20 feet. On the upper half of the ten-mile study section, vegetation was less dense where the water table was more than 20 feet deep. Water losses were estimated to average 1,500 acre-feet annually, or about 1.1 acre-feet per acre. Since transpiration was thought to account for much of this loss, a large percentage of the estimated loss might be

saved following vegetation removal according to Horton and Campbell (1974).

Paired Watershed Studies

Rowe (1963) conducted a paired watershed experiment on the south-facing slope of the San Gabriel Mountains in the San Dimas Experimental Forest of Southern California to determine the effects of clearing along the 1.3-mile main canyon bottom. Vegetation was cut and then sprayed with herbicide to prevent sprouting. About ten per cent of the cleared woodland-riparian area in the treated watershed supported a true riparian growth of alder, maple, willow, and sycamore. The rest of the cleared area supported mixed oak woodland. Following treatment, streamflow increased, primarily in summer and in the initial period of soil wetting during succeeding rainy seasons, when streamflow was lowest and additional water most needed, presumably for irrigation of crops. During the first drying season after clearing (May to December), the flow increased by an estimated 17.4 acre-feet. During the second drying season, the estimated increase in flow was 14 acre-feet. During the first rainy season following treatment (January to April), the estimated increase in flow was 12.8 acre-feet.

No increase in sediment or storm peak discharges from the cleared area was detected. Chemical analysis of runoff revealed no changes in chemical content or total

solids due to treatment. Removal of tree-brush cover shading the stream resulted in higher concentration of green algae (Cladophora spp.), especially in summer flow, based on random observations of comparable periods and flows before and after treatment.

Two small watersheds located in the headwaters of the Hassayampa River, Prescott, Arizona, at 6,000 to 7,000 feet elevation, were instrumented in 1958 to determine streamflow response when channel-side chaparral was converted to a grass-forb cover (Ingebo 1971). After a nine-year calibration period, pelleted feruron was placed by hand under shrubs and trees, predominantly shrub live oak (Quercus turbinella Greene) and true mountain mahogany (Cerocarpus montanus Raf.), on one of the watersheds. Both duration and volume of streamflow increased in the two years following treatment. Streamflow, which was previously intermittent during summer and fall, became continuous. For the two years following treatment, flow increased 0.63 and 0.97 area inches or by 32 and 54 per cent, respectively. In terms of the treated area only (15 per cent of the watershed), the increase was 4.1 and 6.3 inches, respectively. Most of the increase in volume came during the time of major flows, December through April. Shrub and tree kill on the treated area will probably exceed 80 per cent. Native grasses and forbs are increasing on the treated area.

Results of a riparian treatment conducted on the North Fork of Workman Creek in the Sierra Ancha Experimental Forest were reported by Rich et al. (1961). The Workman Creek experimental watersheds are in the humid forest type of central Arizona. Elevation ranges from 6,590 to 7,724 feet and average annual precipitation from 1938 to 1958 was 32 inches.

After 13 years of pretreatment calibration, all Arizona alder and bigtooth maple adjacent to springs, seeps, and streams were cut and the stumps were poisoned with ammate to prevent sprouting. The cut constituted approximately 0.6 per cent of the total basal area of all trees on the 248 acre watershed. No significant increase in annual water yields were obtained following removal of broad-leaved trees along the North Fork, based on comparisons with water yields from the control watershed (Middle Fork). Since riparian trees are deciduous, the riparian cut was also tested for effect on streamflow during the growing season. Flows for post-treatment years did not differ significantly from those for pretreatment years, indicating that the effect of removing riparian vegetation along the stream, if any, was too small to be determined by the instrumentation and the statistical control employed (Rich et al. 1961).

Influence on Other Natural Resources

Timber

When conversion methods are implemented, riparian vegetation is eradicated from the floodplains, windrowed, and later burned or left to decompose. Natural regeneration of riparian species is usually prevented by an annual mechanical or chemical maintenance program.

Riparian vegetation has little commercial value for wood products and has not been used for this purpose. However, some of the larger woody species such as mesquite and saltcedar can be utilized as fence post material and firewood. Some riparian species could possibly be chipped and used as a mulch or in particle board. Cottonwood has some commercial value as discussed below.

Herbage

The amount and quality of herbage production obtained after the initial clearing operation depends on several factors including: (1) the need for a source of viable natural seed in or near the cleared area or a viable seed supply for artificial seeding, (2) adaptability of grass species used to seed the area, (3) time of clearing and/or planting, (4) competition from reinvading riparian vegetation, (5) amount of and timing of annual precipitation, (6) depth to ground water, (7) soil and water salinity, and (8) soil fertility in the area (USDA Soil Conservation

Service 1964). Higher forage production can be expected in those areas where favorable moisture and soil conditions are present.

Once riparian vegetation has been cleared from an area, it may be converted to grasses by natural means or artificial seeding. Natural establishment is dependent on the kinds and amounts of desirable plants remaining after clearing, climate, and supplementary treatment that may be used to accelerate restoration. According to the USDA Soil Conservation Service (1965), satisfactory recovery by the natural spread of grasses can usually be attained where at least ten per cent of the vegetation remaining after clearing consists of uniformly distributed desirable plants, and where competing weeds and woody plants are controlled. If annual rainfall is less than ten inches, establishment of grasses by natural means is difficult and prone to failure (USDA Soil Conservation Service 1965). Sometimes the spread of native plants can be increased by supplementary treatment such as pitting, furrowing, or other kinds of soil disturbance that increases the absorption of rainfall for seedling establishment. However, such treatments are limited in adaptability, costly, and usually temporary (USDA Soil Conservation Service 1965).

Usually grasses must be artificially seeded in areas where dense brush or noncommercial woodlands, which have few or no associated grasses, are cleared, if a post-treatment

grass cover is desired (USDA Soil Conservation Service 1965). This situation is common, particularly in saltcedar communities on many riparian floodplains in Arizona. When rootplows are used, any grasses present probably will be killed, which necessitates the use of artificial seeding (USDA Soil Conservation Service 1964).

Revegetation of floodplains with grasses following clearing in Arizona has not been done on an operational scale except on the San Carlos Indian Reservation. Results of the San Carlos seeding have not been reported. However, several experimental plot studies have been conducted in Arizona following clearing to determine which grass species are appropriate and under what conditions revegetation is feasible.

Three areas on the Snyder floodway near Wellton, Arizona were cleared and seeded to several species of forage plants to determine the feasibility of revegetating floodways after removal of phreatophytes (Powers and Hamilton 1961). Sprinkler and flood irrigations with salty water, and flood irrigation with river water were used to irrigate the sites.

Seeds that were sprinkler-irrigated with slough water containing 5,170 ppm total salts did not appear to germinate. Several species irrigated with river water became established and reached maturity. The "best" stands consisted of blue panic grass (Panicum antidotale Retz),

creeping dropseed (Sporobolus sp.), and common bermuda grass (Cynodon dactylon (L.) Pers.). Species that did not germinate included Moapa alfalfa, dallisgrass (Paspallum dilatatum Poir.), and Rhodes grass (Chloris gayana Kunth.). A few clumps of African stargrass (Cynodon plectostachyus) survived.

With flood irrigation, the best establishment occurred near the center of the floodway where salt content of the soil was relatively low. Poorer establishment occurred near the edge of the floodway where the salt content of soil was comparatively high.

Volunteer establishment of bermuda grasses and blue panic grass in the cleared areas indicated that these species may be suitable for revegetation of floodways at lower elevations in the Southwest. Bermuda grass was the most effective forage cover tested for protecting the soil from movement on vegetated floodways (Cox and Palmer 1948). The bermuda grasses and blue panic grass have value as livestock feed and can be utilized as pasture, green-chop and hay.

The Regional Nursery Division, USDA Soil Conservation Service (1953), Albuquerque, New Mexico, and the Soil and Moisture Conservation Division of the USDI Bureau of Reclamation tested five cool season grasses and 14 summer growing grasses to determine their adaptability for revegetating cleared saltcedar bottom lands on the McMillan

Delta area in New Mexico. Twenty acres of saltcedar were cleared, prepared for flood irrigation, and seeded. The soil was a silty clay with soluble salts ranging between 0.1 and 0.5 per cent. The grasses were irrigated during the first growing season; then irrigation was discontinued to determine which grasses would survive with rainfall conditions of only about 12 inches annually.

The most successful grasses were: tall wheatgrass (Agropyron rigidum Beauv.), alkali sacaton (Sporobolus airoides Torr.), (Aeluropus littoralis, Larvis Trin.), and blue panicum. Species rated next were: weeping lovegrass (Eragrostis curvula Schrap.), boer lovegrass (Eragrostis chloromelas Steud.), sacaton (Sporobolus wreightii Munro), sand dropseed (Sporobolus cryptandrus Torr) and fescue (Festuca sp.). The investigators recommend that the soil be deep plowed and pitted during seedbed preparation to retain natural rainfall, and that irrigation be done with nearly level borders to prevent soil erosion.

Treated areas along the Middle Rio Grande River in New Mexico were revegetated with saltgrass (Distichlis stricta Torr.). These areas are now being grazed by cattle (Schembera 1972).

Following control of tamarisk and establishment of a suitable grass cover, grazing by cattle may help control new invasions and the sprout growth of tamarisk. Gary (1960) investigated the effects of grazing by cattle on the sprout

growth of tamarisk near the Salt River east of Granite Reef Diversion Dam on the Tonto National Forest. Vegetation cover was discontinuous bermuda brass sod over-topped with dense clumps of tamarisk ten to 15 feet in height. At monthly intervals, from June to October, sprout growth from ten randomly selected plants was clipped from three grazed and three ungrazed plots, air dried, and weighed. Weights of grazed plants were less than weights of ungrazed plants, suggesting that the cattle consumed "significant" amounts of sprout growth.

In the same area, Campbell (1966) conducted a study to determine the effects of partial and complete defoliation of tamarisk at various weekly intervals throughout the growing season, and possible water savings as a result of such treatments. It was concluded that mowings in May, July, and September would be necessary to keep foliage succulent and within reach of browsing cattle. According to Campbell (1966), young tamarisk is heavily browsed on floodplains through the Southwest, and if it were mowed at prescribed intervals, a combination of bermuda grass and tamarisk resprouts might produce hundreds of pounds of available forage per year on what would otherwise be relatively low-yield sites.

However, according to Kearney and Peebles (1951), tamarisk is seldom browsed by livestock. Livestock enclosed in a relatively small area containing a limited number of

tamarisk sprouts would keep the tamarisk suppressed by grazing; but in a comparatively large pasture densely populated with tamarisk sprouts, cattle probably would not utilize enough tamarisk to keep it under control (Ogden 1973).

Water use by fluejoint, sedges, saltgrass, tall wheatgrass, and Alta fescue grown in five-foot diameter evapotranspirometers at Winnemucca, Nevada from 1967 through 1969 was reported by Dylla et al. (1972). Saltgrass produced an average of 1.16 tons of hay per acre, and utilized an average of 13.8 inches of water from the beginning of May to the harvest date. The water use efficiency was, therefore, 168 pounds of hay per acre-inch of water used. Alta fescue produced an average 0.64-ton of hay per acre, and used an average of 14.9 inches of water from the beginning of May to the harvest date for a water use efficiency of 86 pounds of hay per acre-inch of water used. Saltgrass, sedges, and bluejoint generally had higher water-use efficiencies than tall wheatgrass and Alta fescue. For any one species, hay yields and water use efficiencies generally decreased as the salinity level in the top foot of soil increased.

Water use efficiencies of the above grass species obtained from tank studies at Winnemucca, Nevada are not applicable to Arizona because of climatic differences between the two states. Most of Arizona has a longer

growing season and higher air temperatures than Nevada. However, the results have been reported to illustrate the type of quantitative data needed in Arizona to evaluate which grass species would be best suited for replacing riparian vegetation on floodplains from the standpoint of water use and herbage production.

The amount of herbage production obtained following the clearing of riparian vegetation depends on many physical factors such as adaptability of grass species and the soil, water, and climatic conditions of the site to be revegetated. These factors have not been adequately investigated. Limited field plot studies have yielded some information on which grass species are best adapted to riparian sites following clearing, but information on post treatment success or failure of operational revegetation projects is scarce. Results of competition between seeded grass species and invading riparian species after clearing treatments have not been reported. Studies of the utilization of tamarisk sprout growth by livestock are inconclusive because they were conducted on limited areas and cannot be extrapolated to conditions prevailing on a large area of floodplain vegetation. Apparently, where revegetation of riparian zones is concerned, there has been little interest or input by range management scientists. More effort has been expended on means to clear and control riparian

vegetation than on the means to revegetate the subsequently cleared areas.

Wildlife and Fish

The Fish and Wildlife Coordination Act, passed by Congress in 1934, insures recognition of fish and wildlife values in water project planning. The Act provides that state and federal fish and wildlife agencies may review, comment and offer recommendations for mitigation on any federal water project. It further stipulates that these reports shall be made an integral part of any project report submitted to Congress by planning agencies.

The following quotation from an article by Bristow (1968, p. 43) helps characterize the position of some wildlife interests regarding the eradication of riparian vegetation:

> If only one or two, or even three phreatophyte areas were planned for clearing, the Department [Arizona Game and Fish] would not be so concerned with these projects. But virtually every valuable phreatophyte area in Arizona is either cleared, authorized for clearing, proposed, or under study for clearing. Riparian vegetation is the key or nucleus of desert habitat. Phreatophyte eradication projects strike at the motherlode, at the heart of our desert wildlife populations. For these reasons, the Department must continually maintain that wildlife interests be given due consideration in water project planning. We ask that planners provide for quality living as opposed to quantity living.

A comparatively large proportion of the literature pertaining to the effects of phreatophyte eradication on

wildlife is concerned with the importance of saltcedar as nesting habitat for doves. Dense tamarisk thickets have been shown to be excellent nesting habitat for both mourning and whitewing doves. A dove nesting study conducted along 45 miles of the Gila River between Gillespie Dam and the confluence of the Salt and Gila Rivers revealed that tamarisk comprised approximately 98 per cent of the total nesting habitat in the study area, and supported 96 per cent of the total nesting population (Shaw and Jett 1959). Dove nesting densities in phreatophyte areas are dependent on several factors (Bristow 1968). Doves prefer to nest in mature saltcedar trees over ten feet in height which have ample second growth limbs to provide suitable nest platforms. Nesting density increases from the edge of the thickets to a point 50 to 100 feet inside. Thus, large blocks of dense vegetation are more productive than narrow strips or small patches. The impenetrable qualities of many saltcedar thickets provide dove nesting areas relatively free of disturbance by humans or predators, and contribute to higher nesting success than would be expected in the surrounding desert.

Doves are seed eaters, and thus proximity to cultivated grain fields for food supplies is another important variable for colony-nesting doves. Whitewings, in particular, prefer to feed in standing fields of small grain crops such as milo, safflower, barley and sunflower

(Bristow 1968). For this reason, according to Bristow (1968), the most productive nesting areas are adjacent to agricultural areas. The extent of whitewinged dove depredations on safflower crops located west of Phoenix were investigated by Kufeld (1965) from 1963 through 1965. Whitewings destroyed 0.55, 1.65, and 3.50 per cent of the total grain produced in a safflower field, one-quarter section in size during 1963, 1964, and 1965, respectively. Kufeld (1965) concluded that whitewing depredation accounts for an insignificant crop loss which does not approach the losses of 25 per cent claimed by growers previously. However, according to Horton (1972), farmers currently tend to avoid crops which produce dove food during the summer months when doves are nesting and feeding their young.

Current densities of doves using saltcedar as nesting habitat suggest that the plant is important. Although the effect of saltcedar removal on dove populations along the Gila River as a whole has not been determined, the quality of nesting habitat appears to be an important factor. According to Shaw (1961), there is evidence that high densities of whitewings were present in mesquite thickets which previously occupied this area, and more must be known about population fluctuation on a statewide level before saltcedar can be given credit for present high populations. The "San Xavier Thicket" (mesquite) south of Tucson also supported heavy concentrations of these doves

at one time, but a gradual lowering of the water table caused most of the trees to die (Bristow 1973). Some birds subsequently attempted to nest in dead trees but without success due to predation and lack of adequate cover. Within two years after the trees began to die, the entire population disappeared and there was no evidence of nesting activity in adjacent desert habitats.

Most human activity affects the carrying capacity (capacity of a habitat to support a given number of plants and animals) of an area for some species of wildlife and the effect is sometimes detrimental. According to Hernbrode (1970, p. 18), "When a flood control or water salvage project removes phreatophytes from the channels of the Gila and Salt Rivers, literally thousands of mourning doves and whitewings are deprived of the finest nesting habitat in America. The loss of song and insectivorous birds is incalculable."

According to Bristow (1968), when 95 per cent of the phreatophyte nesting habitat along the Rio Grande River was cleared, the whitewing dove population in this area declined by an estimated 90 per cent. In an attempt to preserve and rebuild the remnant population, a Texas wildlife agency and private conservation groups purchased land at a cost of 200 to 300 dollars per acre for the production of phreatophytes.

Arizona enjoys comparatively good whitewing and mourning dove hunting. The clearing of saltcedar along river basins, while it may not affect the total population of doves, may scatter them, and thus affect the quality of pass shooting which is popular with hunters. According to Bristow (1968), approximately 95 per cent of dove hunting occurs in areas associated with riparian vegetation of one type or another.

Bottom land riparian vegetation is also habitat for other game and non-game species. Quail, rabbits, and waterfowl depend on the heavy vegetation for escape, nesting and roosting. Big game such as javelina, mule deer, and occasionally bear utilize riparian thickets as a refuge. Big game herds along the riverways are not hunted heavily at this time, but an increase in hunting along the rivers is expected in the future as other hunting areas become more crowded, as suggested by Bristow (1968).

The Arizona Game and Fish Department in cooperation with the USDI Bureau of Sport Fisheries and Wildlife evaluated the effects on wildlife of the Phreatophyte Control and Water Salvage Study conducted on the San Carlos Indian Reservation by the USDI Geological Survey, USDI Bureau of Indian Affairs, and the U. S. Army Corps of Engineers. The effects of clearing approximately 14,000 acres of riparian vegetation within the project area on various species of wildlife were estimated in terms of

hunting man-days lost (Table 8). Losses in wildlife species were estimated from habitat evaluation surveys (composition of vegetative species and density of vegetation); not from wildlife census data.

Table 8. Estimated number of hunting man-days for various wildlife species before and after clearing 13,720 acres of phreatophytes on the San Carlos Indian Reservation (Bristow 1970).

Species	Without Project	With Project	Loss
Dove	20,250	250	20,000
Quail	3,600	100	3,500
Other Small Game	750	250	500
Javelina	1,700	0	1,700
Deer	500	0	500
Ducks	2,200	200	2,000
Geese	500	500	0
	30,500	1,300	28,200

Table 8 indicates that the major loss may be to the production of whitewing and mourning dove.

The Gila River Channel Improvement Project under the direction of the U. S. Army Corps of Engineers was designed to remove most of the riparian vegetation along 54 miles of the Gila River from the Brown's canal to the San Carlos

Indian Reservation. According to Bristow (1970), the project would have removed most of the existing habitat for mourning and whitewinged dove, quail, whitewing pheasant, mule deer, waterfowl, cottontail rabbit, fur bearers, small predators, as well as a number of insectivorous birds. In recognition of the potential detrimental effects of the project on fish and wildlife, and public opposition, the U. S. Army Corps of Engineers redesigned the project through consultation with the Arizona Game and Fish Department. The anticipated detrimental impact on various species of wildlife was diminished by an estimated 25 to 75 per cent by reducing the average width of clearing from 1300 feet to 600 feet (Bristow 1970).

The clearing of riparian vegetation could have a detrimental effect on the rare and endangered wildlife in Arizona. According to Bristow (1968), several birds would possibly disappear from the United States and others would be severely affected by phreatophyte clearing on the Santa Cruz, San Pedro, and Gila Rivers. These birds which are on the Bureau of Sport Fisheries and Wildlife Endangered Species list, include: Mexican duck (Anas diazi Ridgw.), northwestern least grebe (Colymbus dominicus Linn.), black-bellied tree duck (Dendrocygna autumnalis fulgens Linn.), zone-tailed hawk (Buteo albonotatus Kaup), gray hawk (Buteo nitidus Latham.), rose-throated becard (Platypsaris aglaiae Lafr.), thick-billed kingbird (Tyrannus crassirostris

Swains), beardless flycatcher (Camptostoma imberbe ridgwayi Brewst.), green kingfisher (Chloroceryle americana Gmelin.), Anthony's green heron (Burorides viresceno anthonyi Mearns) and the osprey (Pandion haliaetus Carolinensis Gmelin.). Other endangered species which might be affected are the masked bobwhite quail (Colinus virginianus ridgwayi Ridgw.) and the Yuma clapper rail (Rallus longirostris yumanensis Dickey) (Lower Colorado Region Comprehensive Framework Study Appendix XIII 1971).

The use of saltcedar for honey production is important along major floodplains, especially the Rio Grande River (Horton 1972). Bees require pollen to reproduce, and tamarisk provides an early season source of pollen that is important for a "spring build-up" to bolster overwintering bee populations (McGregor 1973). While honey produced from saltcedar is a poor grade of table honey, it is used in the bakery trade, and bees can exist on non-harvested honey until other plants bloom.

Possible effects of saltcedar eradication on beekeepers is illustrated by the following example (McGregor 1973). About 20 years ago bees were first placed in saltcedar thickets during March and April where 300 to 400 colonies (one colony per box) were not uncommon. The colonies were then moved to mesquite bosques in May for the first extract of quality table honey. In June and July, colonies were placed near alfalfa fields before they were

moved to cotton fields (July through October), where two extracts were often possible.

The current pattern, however, is markedly different. Little mesquite habitat is left, due to lowered water tables, and alfalfa fields are avoided since cotton crops are sprayed with insecticide while alfalfa is still in bloom. As a result, colonies are taken directly from saltcedar thickets to cotton fields where an attempt is made to move the bees to another field if that crop is to be sprayed with insecticide.

McGregor (1973) further stated that tamarisk eradication may have serious implications for agriculture. The alfalfa seed industry has already decreased from a 4 million dollar business to just under 300,000 dollars annually as a result of beekeepers avoiding these fields. With beekeepers avoiding alfalfa fields, the bee population is reduced, causing less pollination of the plants. The 15 million dollar cantaloupe business near Yuma would not be possible without bees, since cantaloupe is a bee-pollinated plant.

Fish need quality water at all times. Various chemicals have caused poor water quality in areas of the U. S. in recent years, resulting in fish kills. Over 125,000 fish were destroyed on the Verde River in 1970 after weeds along a drainage ditch were sprayed with a

potent herbicide (Acrolein "mangicide-H") which later entered the river (Rathbun 1970).

The Gila chub (Gila intermedia Grd.) appears to be restricted to the Gila River system of southern Arizona where it presently is most abundant in pools of smaller creeks, in swampy areas, and sometimes in artificial ponds. Changes in aquatic habitats in southern Arizona in the past century have had adverse effects on this species, and it is now absent from many localities of former occurrence (Rinne and Minckley 1970). Phreatophyte removal with chemical retreatment would undoubtedly have serious effects on this fish.

The woundfin (Plagopterus argentissimus Cope.) further illustrates the need for caution. Minckley (1969) reported that this fish, which is found nowhere else in the world, inhabits the lower Virgin River in Arizona. It once existed in the Gila River as far upstream as Tempe, but soon disappeared from the river after Caucasian man began to develop the area. The last woundfin was collected from the Gila River in 1894. These fish have a scientific uniqueness having evolved here in long isolation. Their distributions reflect conditions and drainage relationships that existed in the past.

Campbell (1970) stated that vegetation eradication over large areas should not be implemented until we better understand the biological activity and evolution occurring

on the lands today. The balance or imbalance of biological activity will be partially determined by the severity of vegetation manipulation. Ideally, only riparian vegetation unnecessary for fish and wildlife habitat, control of streambank erosion, or aesthetic value would be manipulated or replaced.

Recreation and Aesthetics

The use of floodplains, or greenbelts, as open space and recreation areas has become popular. The USDI Bureau of Land Management recently set aside public lands along the Gila River from the Texas Hill area to the vicinity of Phoenix, Arizona, as a multiple-use management area with emphasis on protection of whitewing dove nesting habitat (Lower Colorado Region Comprehensive Framework Study Appendix XIII 1971). Another example is the proposed Rio Salado Project for theSalt River floodplain near Phoenix which proposes two lakes four miles in length and a 2,260 acre recreation area containing parks, playing fields, picnic areas, golf course and the future site of the Arizona State fairground (Lower Colorado Region Comprehensive Framework Study Appendix XII 1971).

A number of factors influence the effect that phreatophytes, particularly saltcedar (Tamarisk pentandra Pall.), have on landscape beauty or aesthetics. These factors can be divided into two general categories: those

associated with the phreatophyte vegetation itself, and those variables which are characteristic of the person observing the vegetation. Vegetational factors tend to be comparatively permanent; those associated with the observer are ephemeral and tend to change with the observer's position in space.

Where a river channel is narrow with little opportunity for streamflow to spread, phreatophyte vegetation tends to be confined to a narrow linear band stretching along the river. If the river traverses a broad, flat area where there is greater opportunity for the development of a floodplain, saltcedar, cattails, and other phreatophytes tend to occupy more extensive areas. Generally, the more extensive the phreatophyte vegetation in a floodplain environment, the greater the tendency toward what might be considered an undesirable visual homogeneity and concomitant reduction in landscape quality. However, extensive, mature saltcedar thickets are favored by nesting whitewing doves as pointed out above. Thus, the possible reduction in aesthetic quality associated with broad expanses of saltcedar may be accompanied by enhanced bird populations, which together with other wildlife tend to create a relatively more interesting and attractive visual landscape.

The density of phreatophyte cover may affect the observer reaction to a specific scene. For example, if the vegetation obscures any view of the flowing stream, a

possible positive contribution to landscape variety and beauty is removed from the observer's field of vision.

During the summer, saltcedar coloration tends to be a monotonous green, the impact of which may vary with the extent of the phreatophyte thicket and the characteristics and extent of the surrounding vegetation. However, in areas where the surrounding landscape has only sparse plant life or is brown and barren, the green of phreatophytes across the scene may provide attractive elements of variety and contrast to an otherwise drab visual scene. During the early winter when saltcedar foliage changes color, the scene becomes more varied and colorful so that even extensive reaches of dense tamarisk may become comparatively more attractive visually. After leaf fall in late winter, a brown skeletal landscape feature results, and at this time of year saltcedar may be least attractive.

Observer position affects the relative visual impact of phreatophyte vegetation. If the observer is looking down upon the scene from some vantage point, the general effect is to enhance the positive visual features of the landscape. If the observer is in a position to look down the length of the river from an elevated vantage point, the watercourse and its associated vegetation create a potentially interesting focal landscape in which the observer's eye is carried naturally from immediate foreground to the horizon. If the elevated observer is in a place where he can look across

the river channel, the river and phreatophytes create a linear, color, horizontal belt or band which stretches across the visual scene, possibly producing a different effect.

Phreatophyte vegetation, viewed from a normal position (observer's line of sight coincides with the dominating elements of the landscape) along the river tends to create an enclosed landscape with green walls delineating the contrasting water base of the scene. From any other normal or inferior position (observer is level with or below the surrounding landscape), dense riparian vegetation viewed at close range may not be particularly pleasing aesthetically; the effect tends to be one of blandness and monotony.

Generalizations about the visual quality of phreatophyte vegetation in the southwestern landscape are subjective and difficult to make as the preceding discussion indicates. The extent and density of the phreatophytes, the nature of associated vegetation and physical relief, the season of the year, the position and distance of the observer relative to the saltcedar are all important variables. Different combinations of the variables can produce positive or negative effects. Each area and particular scene should be analyzed individually to properly judge the contribution of phreatophyte vegetation to the visual quality of the landscape in question.

Mechanical or chemical treatments remove riparian vegetation from river channels and floodplains. Usually grasses are planted or encouraged to invade the treated floodplain. A successful conversion replaces one type of green belt with another. Aesthetically, grass may be preferred by many observers. Cattle, grazing on a grassy expanse of riverside land may create a more visually appealing scene than a dense expansive thicket of saltcedar. Making the river more visually accessible by replacing phreatophytes with grass may be a desirable aesthetic enhancement.

A possible severe aesthetic problem with mechanical clearing of phreatophytes may result from disturbance of the soil, and the barren landscape scattered with debris from the clearing operations, that could result. Heavy machinery scarifies soil and eliminates some desirable understory grasses that are associated with the saltcedar community. Debris should be windrowed or piled and burned to help alleviate the undesirable visual effects of this treatment.

Other

The potential danger of contaminating streamflow or ground water with chemicals applied to control riparian vegetation should not be overlooked. Studies on forested watersheds indicate that environmental contamination may

result from use of herbicides and petroleum carriers in forest operations. However, the herbicides and petroleum carriers generally are not harmful to fish and wildlife as discussed below.

The characteristic movement and persistence of a chemical in the environment is called its behavior. According to Montgomery and Norris (1970), the behavior of a chemical in the environment will largely determine its residue levels in air, water, soil, and plants, and hence the likelihood and level of its subsequent exposure to man and animals.

Montgomery and Norris (1970) gave the following examples of the interaction between the properties of a chemical and the environment. The vaporization of herbicide into the atmosphere is governed by the interaction of the chemical with treated surfaces and the temperature of the environment. The susceptibility of herbicide to metabolism by plants and soil microorganisms will determine its persistence in plants and soil. The water solubility and absorption characteristics of a chemical govern its mobility in soil and, therefore, the degree of surface or ground water contamination.

A riparian watershed treatment of 9.3 lbs/acre of soil-applied 4-amino-3,5, 6-tri-chloropicolinic acid (picloram pellets) for the control of chaparral brush on Three Bar Watershed B located in the Mazatzal Mountains of

central Arizona resulted in the movement of detectable amounts of picloram into the stream water (Davis, Ingebo, and Pase 1968). The highest concentration detected in streamflow was 0.37 ppm. After 16 months and 40 inches of accumulated rainfall, picloram was no longer detectable in the stream.

Leaching of picloram is inversely related to the extent that it is sorbed by the soil, and to the water-holding capacity of the soil. It is most readily leached through sandy montmorillonitic soils low in organic matter, and leached with greatest difficulty through lateritic clay soils and muck soils (Dow Chemical Company 1963). Picloram not lost through leaching is highly persistent and is only slowly decomposed by soil micro-organisms (Hanmaker et al. 1963).

Toxicological studies have shown that picloram is low in toxicity to a variety of test animals, including avian, mammaliam, and aquatic species, and that it does not represent a hazard to livestock or wildlife when used as recommended (Lynn 1965). However, Davis et al. (1968) reported that crops such as alfalfa, sugar beets, safflower, and soybeans are sensitive to picloram and the use of picloram-contaminated water for irrigation purposes could cause crop damage.

In western Oregon, 2,4-dichlorophenoxyacetic acid (2,4-D), 2,4,5-trichloro phenoxyacetic acid (2,4,5-T), or a

1:1 mixture of these low volatile esters in diesel oil were applied by helicopter at rates of about two lb/acre for bush control on forest areas ranging in size from five to 100 acres (Norris, Newton, and Zavitkowski 1965). Detectable, but comparatively low quantities of herbicide were found in almost all streams from which samples were taken, ranging from less than 0.5 parts per billion (ppb), the minimum level of quantitative detection, to about 70 ppb. Herbicide residues persisted in streamflow for only a short time, and in most cases, the level fell below 0.5 ppb a few days after spraying. Size of the area treated and amount of stream surface exposed in the treated area were significant factors in determining the amount of residue found in streamflow.

According to Montgomery and Norris (1970), aerial applications of 2,4,5-T to forest lands result in an initial low-level, short-term stream contamination which does not represent a significant hazard to fish or animals. Extensive absorption and degradation of 2,4,5-T in the forest floor prevents its movement from treated areas to surface and ground waters. The primary exposure of animals to 2,4,5-T will be by ingestion of treated vegetation. Rainfall, growth dilution, and degradation markedly reduce herbicide residues within a few weeks after application. Furthermore, 2,4,5-T is low in acute toxicity and is rapidly excreted by animals (Montgomery and Norris 1970).

The effect of phenoxy herbicides on aquatic life was investigated on the Wilson River watershed in western Oregon, an important spawning system for anadromous fish. A total of more than 600 acres was sprayed with a mixture of one lb., 2,4-D and one lb., 2,4,5-T per acre in 9-1/2 gal. of diesel oil carrier (Tarrant and Norris 1967). Observations made with live cages containing salmon fry and samplings of streambottom organisms did not indicate any effect in terms of fish mortality or numbers of streambottom organisms.

No trace (level of detection not specified) of a mixture of 2,4-D and 2,4,5-T herbicides in surface streamwater was found after chemical removal of woodland-riparian vegetation on the San Dimas Experimental Forest in California (Rowe 1963). In the same area, vegetation sprayed with the same combination of chemicals produced residues in adjacent streams but never more than 0.09 ppm (Krammes and Willets 1964).

Immediately after streamside vegetation was mist-sprayed with a 2,4,5-T ester in northeastern United States, herbicide concentrations of 40 ppb were detected in the streamwater by odor tests (Sopper, Reigner, and Johnson 1966). Four hours later, the herbicide concentration had decreased to 20 ppb. Only after the first large storm was any further herbicide odor (ten ppb) detected. Contamination was detectable only within the treated reach of stream, and no conatmination was ever found in a downstream sample.

Phenols, when chlorinated, form chlorophenols. The chlorophenols have low odor and taste thresholds and may be detected by humans in concentrations as low as 0.3 ppb (Sopper et al. 1966).

The apparent lack of long-term water pollution after herbicides are carefully applied to forest vegetation is due primarily to the comparatively rapid rate at which their residues are degraded in forest litter. Both 2,4-D and 2,4,5-T are degraded in forest litter but at different rates; 2,4,5-T shows only a slight increase with time (Norris, Newton, and Zavitkowski 1966). More than 85 per cent of the 2,4-D applied to forest litter in laboratory studies was decarboxylated within 300 hours compared to less than 25 per cent of the 2,4,5-T so applied.

Diesel oil, a principal carrier used with forest herbicides, constitutes from 80 to 90 per cent of the spray solution. Tarrant and Norris (1967) reviewed a number of German studies concerning possible contamination of soil and water by the diesel oil carrier. The general conclusion was that diesel oil is unobjectionable so long as prescribed dosages are observed. In California, Rowe (1963) found two to 30 ppm of diesel oil in streamwater after chemical treatment of woodland-riparian vegetation with a herbicide solution. In the same area, Krammes and Willets (1964) found no trace of diesel oil, using analytical methods

sensitive to one ppm, after a similar application of herbicide spray.

While substantial studies have been conducted on the behavior of herbicides in the forest environment, less attention has been given to herbicides used in the desert environments for phreatophyte eradication. Primary concern in phreatophyte spraying programs has been to avoid contaminating nearby croplands.

The potential for both water and wind erosion increases after the mechanical eradication of channel and floodplain vegetation until grasses and woody phreatophytes invade the area. The amount of erosive damage experienced will depend on the nature of the stream, topography, climatic characteristics (precipitation amount and intensity, wind speeds and direction), soil types, and the rapidity with which new vegetation is established.

Economic Considerations

Direct Returns to the Land

Depending on conditions as described in the hydrology section above, mechanical or chemical clearing of riparian vegetation along streams may increase the water supply by up to 2.5 acre-feet per acre per year. According to Howe (1971), benefits of an increased water supply to irrigated agriculture include (1) an increase in farm output due to more intensive cultivation, higher valued crops, and expanded

acreage and (2) an increase in net incomes after allowing a competitive return on capital of industries either supplying, transporting, or processing the increased agricultural production, provided these increases would not have occurred in the absence of irrigation. Such increased incomes are derived from greater use of an under-used plant or economics of scale. An analysis of benefits from irrigation is difficult because of the many public price support and acreage retirement programs that tend to change prices from what they would be in a free market.

Clearing the channel of riparian vegetation may prevent flood flows from moving out of the channel onto floodplains where it may destroy or damage property. According to Howe (1971), the benefits of clearing are (1) the damage prevented to present and future floodplain property that would exist in the absence of the flood control project and (2) from new occupancy that finds the floodplain profitable because of the new degree of protection. The value of this flood control will vary from place to place throughout Arizona depending on the value of property on the floodplain. Generally, the property value of floodplains is highest near municipalities, intermediate for cultivated lands, and lowest in desert areas.

No published field studies have been conducted to determine the actual increases in forage grasses or animal

unit months which might be derived after clearing riparian vegetation from floodplains in Arizona.

Direct Cost of Implementation

Costs associated with the clearing of riparian vegetation by mechanical means are available. Most of the information is based on a dollar cost per acre, developed from an overall cost for a specific area. Unfortunately, in some cases, there is a lack of definitive information about specific conditions such as the type and density of vegetation removed.

The cost of eradicating growth varies with the type and combination of mechanical equipment employed, size of area treated, vegetation density, plant species present, and terrain.

Table 9 summarizes cost data compiled by the USDI Bureau of Reclamation for clearing operations on the Rio Grande River in New Mexico from 1958 through 1965. The figures include depreciation, repairs, fuel oil, and labor. They do not include stacking or burning costs (estimated to average ten dollars per year), overhead, administrative supervision, or vehicle expenses. According to the USDI Bureau of Reclamation Five (1963), for initial clearing the approximate costs per acre (based on 1962 values of the dollar) using the root plow, rock rake, and 84-inch rotary mower were 20 to 25 dollars, 20 to 25 dollars, and seven to

Table 9. USDI Bureau of Reclamation cost figures for clearing and controlling woody plants along the Rio Grande River in New Mexico (Lowry 1966).

	1958[b]	1959	1960	1961	1962	1963		1964		1965		
	CLEARING											
						RG[a]	MRG[a]	RG	MRG	RG	MRG	Region 2
Root Plow	--	--	--	--	$10.60	$7.40	$ --	--	--	--	---	---
Rock Rake	$20.00	$12.50	$11.00	$6.40	--	--	--	--	Contract (6,286 a.) $288,990	(46 a.)	---	---
Rotary Cutter	9.00	8.00	9.00	7.75	--	--	--	--	--	--	--	---
	CONTROL											
Root Plow	--	--	--	--	$10.25	$3.05	(1,950 a.) $7.67	(1,500 a.) $6.25	(957 a.) $7.62	(2,434 a.) --	(633 a.) $9.90 (1,455 a.) $9.40	---
Rotary Cutter	2.30	2.30	1.30	1.79	1.85	1.70	(2,561 a.) $2.38	(2,450 a.) $1.70	(1,805 a.) $4.10	(1,308 a.) --	(2,964 a.) $1.95	(610 a.) $4.00Contract
Ground Sprayer	--	--	9.00	--	9.00	8.90	(150 a.) $10.77	(150 a.) $8.90	(2,000 a.) $5.93	(290 a.) --	(1,600 a.) $9.65	(163 a.) ---
Helicopter	--	--	--	--	--	--	--	--	(1,850 a.) $12.00	--	(Floodway) (1,313 a.) $10.62 (Prototype) (1,021 a.) $12.83	(411 a.) $11.47
Disc	--	--	--	--	--	--	$10.40	--	--	--	--	---
Brush Chopper	--	--	--	--	--	--	--	--	(350 a.) $4.86	--	(315 a.) $1.68	---

[a]RG = Rio Grande River; MRG = Middle Rio Grande River.

[b]Cost figures are based on dollar value for each individual year (1958 to 1965).

ten dollars, respectively. These figures do not include costs for overhead, supervision, or for the stacking and burning of debris. The USDI Bureau of Reclamation also found that for maintenance control of cleared areas, the rotary mower cost an average of two dollars per acre based on a total of 18,000 acres cleared from 1958 through 1963. During this same period, the costs of using the root plow for maintenance control varied from three to ten dollars per acre depending on the type of soil in which the machine was operating and the amount of regrowth. On the Middle Rio Grande Project, over 6,000 acres of plant growth was cleared at a total cost that averaged 60 dollars per acre from 1957 to 1959 based on dollar values for 1959 (Frost and Hamilton 1960).

A control program to clear saltcedar from the Gila River was conducted by the Wellton-Mohawk Irrigation and Drainage District, Wellton, Arizona in 1958. A strip 400 feet wide and 55 miles long was cleared of all saltcedar using rootplows on caterpillar tractors. International TD-18 tractors with front-mounted rakes were used to pile the debris which was later burned. The cost per acre for clearing and brushing between sites was determined by dividing the number of acres cut and raked each day by the costs of the Wellton-Mohawk Irrigation and Drainage District each day.

The approximate rootplowing costs per acre at different percentages of areal cover and density between sites were reported by Frost and Hamilton (1960) and are given in Tables 10 and 11. The highest cost was 21 dollars per acre on sites where average density and cover were low. Raking costs ranged from seven to 16 dollars per acre. There was no apparent relationship between raking cost and areal cover, but this may have been due to the small range between high and low areal cover and density.

Table 10. Undercutting machinery costs between sites ($15.00 per tractor hour) on the Gila River near Wellton, Arizona (Frost and Hamilton 1960).

Sites[a]	Cost Per Acre (1958)	Average Vegetative Cover	Average Plant Count
	(Dollars)	(Per Cent)	(Plants Per 20 by 100 Foot Plot)
J-L	21	52	17
D-E	17	41	16
G-H	17	36	14
M-N	15	47	9
I-J	14	44	9
N-O	8	32	6
H-I	7	36	11
O-P	7	28	5

[a]Letter designation of 18 sites along the Gila River which varied from 0.5 to 4.5 miles apart.

Table 11. Raking machinery costs between sites ($12.00 per tractor hour) on the Gila River near Wellton, Arizona (Frost and Hamilton 1960).

Sites[a]	Cost Per Acre (1958)	Average Vegetative Cover	Average Plant Count
	(Dollars)	(Per Cent)	(Plants Per 20 by 100 Foot Plot)
F-H	16	33	13
I-J	11	41	9
D-E	9	36	14
M-O	7	39	8
H-I	7	36	11

[a]Letter designation of 18 sites along the Gila River which varied from 0.5 to 4.5 miles apart.

The cost of clearing riparian vegetation when conducted by government agencies varies depending on whether it is accomplished by force account (work accomplished by government employees and equipment) or by contract. For example, the cost for clearing approximately 6,000 acres near the Caballo Reservoir, New Mexico, by the USDI Bureau of Land Management from about 1958 to 1963 averaged approximately 20 dollars per acre according to Lowry (1966) when done by force account. On 6,400 acres near Bernardo, New Mexico, the cost for clearing was 45 dollars per acre when accomplished by contract in 1964 (Lowry 1966). Some of this difference in cost was due to a denser growth of

vegetation and a more sandy unstable soil at Bernardo compared to the less dense vegetation and stable soil at the Caballo Reservoir site. In addition, the contractor was required to stack the debris at Bernardo, while this step was omitted at the Caballo Reservoir site.

The USDI Bureau of Reclamation Three (1963) developed estimates for the mechanical eradication of 140,000 acres of phreatophytes along the Lower Colorado River floodplain from Davis Dam to the Arizona-Mexico boundary based on 1962 prices. Only data from other phreatophyte clearing operations that were representative of the plant types and densities of growth existing within the study area were used. Data for large acreages (larger than one square mile) were used to compute a weighted field cost per acre. Prices included costs of stacking and burning as well as indirect costs for surveying, inspection, and administration of contracts. Based on work done by contract for mechanical clearing, the total estimated costs per acre in 1962 were 50 dollars. Mechanical regrowth control by force account, including costs for stacking and burning and indirect costs, was estimated at five dollars per acre.

A prototype clearing of 6,258 acres was conducted in 1964 along a 14-mile reach of the Rio Grande River in Socorro County, New Mexico, by the USDI Bureau of Reclamation (1965b) to determine the actual contract costs, without the contractor's profit, for clearing phreatophytes by

various mechanical methods and in varied types of cover. The major plant species consisted of saltcedar, cottonwood, willows, mesquite, and tornillo, in descending order of occurrence. Three types of cover including "heavy," "medium," and "light" were located in four separate areas.

Area 1. This area was representative of heavy-type clearing. Prior to clearing, four general vegetative conditions existed.

1. The overstory consisted of an average cottonwood density of 50, 18- to 24-inch diameter trees per acre with an average underbrush density of 50, five- to ten-foot high bushes per acre. The underbrush consisted of saltcedars, willows, and Russian olive. These conditions were representative of 32 per cent of area 1.
2. The cottonwood overstory comprised an average density of ten, 18- to 24-inch diameter trees per acre with an average underbrush density of 50, ten-foot high bushes per acre. The underbrush consisted of saltcedar, willows, and Russian olive.
3. An average cottonwood density of 20 to 30, eight-inch diameter trees per acre constituted the overstory. The underbrush consisted of a mixture of saltcedar, willows, and Russian olive with an average density of 70 to 190, ten-foot high bushes

per acre. Areas 2 and 3 combined represented vegetative conditions on 32 per cent of area 1.

4. On 36 per cent of area 1, the average vegetative condition consisted of 110 to 380, ten- to 15-foot high saltcedars per acre.

Area 2. This area was representative of medium-type clearing. Prior to clearing, the general vegetative condition consisted of an average of 110 to 380, 10- to 15-foot high saltcedars per acre.

Area 3. This area constituted the second of the two study areas of medium-type clearing. Prior to clearing, two general vegetative conditions existed.

1. Saltcedars covered 88 per cent of area 3 and had an average density of 110 to 380 ten- to 15-foot high bushes per acre.
2. The overstory consisted of an average cottonwood density of two, 12- to 18-inch diameter trees per acre. Brush throughout the area was comprised of an average of 200, ten-foot high bushes of mixed tornillo, Russian olive, saltcedar, and willows. This vegetative condition represented 12 per cent of area 3.

Area 4. This area constituted the study area of light-type clearing. Prior to clearing, three general vegetative conditions existed.

1. An average of 90 to 140, five- to ten-foot high willows per acre was representative of one of the vegetative conditions in area 4.
2. An average of 730 to 2,600, five-foot high saltcedars per acre together with vegetative condition 1 described above covered 62 per cent of area 4.
3. Saltcedar with an average of 330 to 1,660, ten-foot high stems per acre covered 38 per cent of area 4.

Table 12 itemizes the final estimated clearing costs for the various procedures used by the contractor in clearing the study areas. The results indicate that clearing heavy vegetation in Area 1 cost 45 dollars per acre, while clearing in Areas 2 and 3 with medium vegetation cost 32 and 29 dollars per acre in 1964. Clearing of light vegetation in Area 4 cost 45 dollars per acre. Clearing of small (five-foot-high), dense, and pliable light-type brush proved to be more difficult than did clearing of heavier cover.

The cost per acre for raking the cleared brush into windrows ranged from 59 to 81 per cent of the total per acre clearing cost. If the brush raking step could be eliminated from phreatophyte clearing methods, considerable savings in

Table 12. Bernardo prototype area clearing cost data (1964) -- Cost per hour and acre; USDI Bureau of Reclamation (1965b).

Study area	Clearing procedure	Caterpillar tractors			Farm ro
		Tractor hours[d]	Rate per hour	Cost for unit	Tractor hours[d]
Area 1	Tractors with cutters	362	$10.60[b]	$3,837.20	
480 acres	Tractors with rakes	564	10.60	5,978.40	
Heavy	Tractors with rotary mowers				84
Total cost					
Area 2	Tractors pulling chain	24	10.60	254.40	
400 acres	Tractors with cutters	233	10.60	2,469.80	
Medium	Tractors with rakes	296	10.60	3,137.60	
	Tractors with rotary mowers				40
Total cost					
Area 3	Tractors pulling chain	128	10.60	1,356.80	
680 acres	Tractors with cutters	109	10.60	1,155.40	
Medium	Tractors with rakes	602	10.60	6,381.20	
	Tractors with rotary mowers				123
Total cost					
Area 4	Tractors pulling chain	136	10.60	1,441.60	
920 acres	Tractors with rakes	1428	10.60	15,136.80	
Light	Tractors with rotary mowers				584
Total cost					

[a] Exclusive of contractor's management cost and home office bookkeeping.

[b] Composite A.E.D. rental rate on monthly basis for contractor's Caterpillar

[c] Average rental rate determined from local equipment dealers for farm tract

[d] Actual equipment field operating hours.

[e] Cost per acre unavailable because the number of acres on which the equipme

Note: In Study areas 2 and 3 there is no direct summation relationship betw procedures were used. In Study Areas 1 and 4 all clearing procedures were used on

tractors with tary mower		Operators and supervision			Fuel, oil, and lubricants			Parts and	
Rate per hour	Cost for unit	Hours	Rate per hour	Cost for unit	Hours	Rate per hour	Cost for unit	Hours	Rate per hour
		362	$3.19	$1,154.78	362	$1.90	$687.80	362	$5.49
		564	3.19	1,799.16	564	1.90	1,071.60	564	5.49
$2.10[c]	$176.40	84	3.19	267.96	84	0.65	54.60	84	1.46
		24	3.19	76.56	24	1.90	45.60	24	5.49
		233	3.19	743.27	233	1.90	442.70	233	5.49
		296	3.19	944.24	296	1.90	562.40	296	5.49
2.10	84.00	40	3.19	127.60	40	0.65	26.00	40	1.46
		128	3.19	408.32	128	1.90	243.20	128	5.49
		109	3.19	347.71	109	1.90	207.10	109	5.49
		602	3.19	1,920.38	602	1.90	1,143.80	602	5.49
2.10	258.30	123	3.19	392.37	123	0.65	79.95	123	1.46
		136	3.19	433.84	136	1.90	258.40	136	5.49
		1428	3.19	4,555.32	1428	1.90	2,713.20	1428	5.49
2.10	1,226.40	584	3.19	1,862.96	584	0.65	379.60	584	1.46

D-8 and D-6 tractors operating on average of 192 hours per month.

or and mowing unit.

nt was used is unknown.

een the individual clearing procedures costs per acre and the total cost per acre because the same number of acres.

repairs	Moving equipment in and out			Total clearing costs[a]			
Cost for unit	Hours	Rate per hour	Cost for unit	Cost for operation	Cost per hour	Cost per acre	Per cent of total
$1,987.38	362	$1.43	$517.66	$8,184.82	$22.61	$17.05	38
3,096.36	564	1.43	806.52	12,752.04	22.61	26.57	59
122.64	84	0.51	42.84	664.44	7.91	1.38	3
				$21,601.30	$53.13	$45.00	100
121.76	24	1.43	34.32	542.64	22.61	e	
1,279.17	233	1.43	333.19	5,268.13	22.61	13.17	41
1,625.04	296	1.43	423.28	6,692.56	22.61	27.89	
58.40	40	0.51	20.40	316.40	7.91	1.32	
				$12,819.73	$75.74	$32.05	100
702.72	128	1.43	183.04	2,894.08	22.61	4.26	15
598.41	109	1.43	155.87	2,464.49	22.61	e	
3,304.98	602	1.43	860.86	13,611.22	22.61	20.02	68
179.58	123	0.51	62.73	972.93	7.91	1.43	5
				$19,942.72	$75.74	$29.33	100
746.64	136	1.43	194.48	3,074.96	22.61	3.34	8
7,839.72	1428	1.43	2,042.04	32,287.08	22.61	35.09	81
852.64	584	0.51	297.84	4,619.44	7.91	5.02	11
				$39,981.48	$53.13	$43.45	100

of the difference in the number of acres on which the various clearing

initial contract costs could be realized. However, considering an ensuing period of maintenance, the high initial cost of a complete operation including raking, which allows cheaper maintenance equipment to operate, may be relatively more economical in the long run.

The aerial application of herbicides by helicopter was used extensively in New Mexico on the middle Rio Grande floodway and in areas where annual reinvasion is common. The cost of this work during 1964 and 1965 varied from eight to 13 dollars per acre when accomplished by contract (Lowry 1966). In 1968, the cost for spraying 1400 acres by helicopter in the same area averaged about 11 dollars an acre (Schachterle 1969a).

The cost for operating groundspray rigs has averaged from six to nine dollars per acre in New Mexico from 1960 to 1965 depending on the rate of chemical application and type of material used (Lowry 1966).

To summarize, costs for the initial clearing of riparian vegetation with heavy equipment such as the root-plow and rock rake have ranged from approximately seven to 50 dollars per acre from 1958 through 1965. The range in costs are due to differences in plant species, density of vegetation, and terrain on various clearing sites and to inflation. Costs for raking, stacking or burning the debris produced during clearing operations ranged from five to 16 dollars per acre between the years of 1958 and 1965.

However, in one large clearing operation, the costs of raking the cleared brush into windrows cost between 26 and 35 dollars per acre in 1964. The cost of maintaining cleared areas in riparian zones with the rotary mower, brush chopper, and disc ranged between approximately two and 12 dollars per acre for the years of 1958 through 1965. In some situations, the clearing of small, dense and pliable brush stands may cost as much as clearing dense stands of older and larger phreatophytes. Chemical control by aerial or ground means ranged between six and 13 dollars per acre from 1960 to 1965.

Costs for various mechanical and chemical control and maintenance methods presented in this section were adjusted to April, 1974 costs by the use of the wholesale price index (U. S. Department of Commerce, Bureau of the Census 1974). The high and low costs for each method at April, 1974 prices are given in Table 13. The 1974 costs range between 11 and 80 dollars per acre for mechanical control; three to 19 dollars per acre for mechanical maintenance of cleared areas; and ten to 21 dollars per acre for chemical maintenance of cleared areas. Although these cost figures of conversion treatments may appear high, when subsequently discounted over 50 years they seem more reasonable. These cost figures are discussed in more detail in the section below concerned with economic constraints.

Table 13. Approximate low and high treatment costs per acre, low and high treatment costs for 5,000 acres, and annual equivalent costs for 5,000 acres over a 50-year period for mechanical, mechanical-chemical combination, and seeded grass conversion treatments -- Data derived from the literature and adjusted to April, 1974 dollar values.

Inputs	April, 1974 Treatment Cost per Acre (dollars)		April, 1974 Treatment Cost for 5,000 Acres (dollars)		April, 1974 Annual Equivalent Costs (50 yrs. at 8%) for 5,000 Acres (dollars)	
	Low	High	Low	High	Low	High
Initial Tmt.	11	80	55,000	400,000	4,500	32,700
Raking or Burn	8	26	40,000	130,000	3,270	10,625
Annual Mechanical Maintenance	3	19	15,000	95,000	15,000	95,000
Total Costs for Mechanical Tmt.						
Chemical Maintenance	10	21	50,000	105,000	50,000	105,000
Total Cost for Mechanical Tmt. with Chemical Maintenance[a]					57,770	148,325

Table 13.--Continued

Inputs	April, 1974 Treatment Cost per Acre (dollars)		April, 1974 Treatment Cost for 5,000 Acres (dollars)		April, 1974 Annual Equivalent Costs (50 yrs. at 8%) for 5,000 Acres (dollars)	
	Low	High	Low	High	Low	High
Seeding	6	18	30,000	90,000	2,450	7,360
Chemical or Mechanical Maintenance	3	21	15,000	105,000	15,000	105,000
Total Cost for Seeded Grass Conversion Tmt.[a]					25,220	155,685

[a]Costs for initial treatment and raking or burning costs are included.

Opportunity Costs

A given resource often has several possible alternative uses which may be mutually compatible or, in some cases, incompatible. If uses are incompatible, a means of measuring benefits foregone by choosing one alternative over another is useful for land managers. This is the concept of opportunity costs. Ferguson (1969) defines the opportunity costs of producing one unit of commodity X as the amount of commodity Y that must be sacrificed in order to use resources to produce X rather than Y.

If mechanical removal of phreatophytes is undertaken as opposed to leaving the vegetation in its natural state, there will be opportunity costs involved. Basically, these will reflect wildlife and recreation outputs foregone.

Much opposition to phreatophyte control is a result of the impending loss of dove habitat. Tamarisk is considered by some to be excellent habitat for both mourning and whitewing doves, which are important game species in Arizona. In addition, small game species, waterfowl, and occasionally larger animals use riparian areas for shelter and food. Phreatophyte control may also have an adverse effect on fish habitat and may reduce fishing opportunities in some situations.

If a monetary value could be placed on these animals, i.e., their value as game for hunters and fisherman, a dollar value for the opportunity cost could be

determined. One approach to the problem (Maddox 1972) is to use the cost of raising birds and fish on game farms and fish hatcheries necessary to maintain the population of birds and fish prior to the clearing of phreatophytes. This method is only practical when similar habitat is available for stocking the replacement game birds or fish. However, there is no general agreement as to how intangible opportunity costs can be determined. Current and future research may help answer this question, but such results are not presently available.

A similar problem is found in considering recreation and aesthetics. In addition to game values, wildlife has aesthetic value for some observers and photographers. A monetary value for aesthetic experience is also difficult to determine.

Conversion of the riparian zone may have visual impacts. Depending on individual tastes and preferences, the converted riparian area may or may not be as aesthetically pleasing as the original. Again, any opportunity costs involved would be difficult to quantify.

Mechanical treatments have several opportunity costs. With present knowledge, the decision-maker will have to decide whether or not these costs outweigh the benefits derived from increased water yields and flood control, and it will have to be done using something other than dollars for comparison.

Opportunity costs involved with mechanical-chemical treatment combinations are similar to mechanical treatment alone except for two instances. First, chemical control generally causes less destruction to grass so that greater forage production may be expected. However, using chemical control may increase the probability of a reduction in water quality due to runoff. If reduced water quality is significant, it would have to be included as an opportunity cost. Again, with present knowledge, it is difficult to place a monetary value on reduced water quality.

Extent of Current Implementation

The Phreatophyte Subcommittee of the Pacific Southwest Inter-Agency Committee conducted a phreatophyte treatment survey for the State of Arizona in August 1969. The survey indicated that 10,953 acres of phreatophytes have been cleared by mechanical means; 19,581 acres were currently being cleared; and 75,010 acres were being planned for clearing. The agencies which conducted these operations include the USDI Bureau of Indian Affairs, the USDI Bureau of Land Management, the USDI Bureau of Reclamation, the U. S. Army Corps of Engineers, the International Boundary and Water Commission, and several irrigation districts.

Riparian woodland treatments along perennial streams are still in the experimental stage, with the

exception of the Salt River Project's cottonwood thinning program along the Verde River where 1,029 acres of riparian vegetation were thinned (Gill 1969).

In Arizona, 2,286 acres of phreatophytes have been treated by chemical means (Pacific Southwest Inter-Agency Committee 1969).

Potential for Future Implementation

Vegetative-Physiographic-Climatic Constraints

Vegetative, edaphic, geologic, hydrologic, and climatic factors combine to influence the amount of water lost by evapotranspiration in riparian zones. These factors include vegetative density, species composition, stage of growth, soil type, soil and water salinity, depth to ground water, amount and seasonal distribution of precipitation, solar energy, relative humidity, wind speed, and length of growing season. Many of these factors are interrelated and vary over time and space.

Although the processes involved are complex and interrelated, evidence indicates that areas with depths to ground water of four to 20 feet, low soil and water salinity, and dense, young, vigorous stands of the heavier water using species may yield water savings of up to 2.5 acre-feet per acre annually after riparian vegetation is removed (Hanson et al. 1972). Some portion of the 2.5 acre-feet of water

salvaged will be lost when reinvading or planted vegetation becomes established. On floodplains with either comparatively shallow or deep water tables, high soil and water salinity, and old relatively mature and scattered species of intermediate water using capacity conversion treatments may yield little or no water savings after the vegetation is removed (Horton and Campbell 1974).

Horton and Campbell (1974) defined four types of floodplain zones based on water table depth and vegetation structure (primarily saltcedar) for management purposes. A brief description of each zone is given below.

Zone 1. This zone has a shallow water table (three to four feet or less) with a vigorous grass cover and scattered, dwarfed saltcedar. The saltcedar is stunted as a result of restricted root growth caused by high water tables. Water savings would be low if the saltcedar were removed because of a compensating increase in evaporation from the high water table.

Zone 2. The water table is approximately three to eight feet deep and is readily available to roots of established grasses, but not so shallow as to restrict the growth of saltcedar. In many areas, saltcedar has crowded out the competing grasses and is the dominant vegetation. Water savings of up to two acre-feet per acre may be possible with

the removal of saltcedar; however, this amount would be decreased as replacement cover became established.

Zone 3. The water table is beyond the roots of grass, but within the reach of the roots of saltcedar. Good water salvage opportunities exist in this zone; however, erosion and revegetation may be a problem because of a relatively deep water table (ten to 20 feet).

Zone 4. The water table is too deep for saltcedar to thrive and only widely scattered saltcedar shrubs survive on the floodplain. There is little opportunity for water salvage under these conditions.

According to Horton and Campbell (1974), potential for water salvage is highest in zones 2 and 3 and lowest in zones 1 and 4. In some floodplain areas, there may be a change from one zone to another as a result of clearing the vegetation. For example, zone 2 might be converted to zone 1 after clearing as a result of a raised water table. If this situation should occur, little or no water salvage could be obtained in the area.

The need for and use of salvaged water in a particular geographical area with respect to the acreage of treatable riparian vegetation will have an influence on the potential for future implementation. In general, the closer treatable riparian vegetation is to the point of water use,

the higher the potential for water salvage by vegetation management.

It would be unwise to clear all riparian vegetation in Arizona for water salvage. However, assuming that all vegetation in the riparian zones of Arizona was cleared, a rough indication of the maximum potential water yield can be obtained which may be useful for future planning purposes. Assuming that Arizona has 279,600 acres of riparian vegetation (Babcock 1968), and that two acre-feet per acre of water per year could be salvaged by removing this vegetation, an annual yield of 559,200 acre-feet of water could be realized. Consideration for other uses of the land such as wildlife, recreation, and aesthetics, together with the physical factors affecting water yields and land ownership, would cause a considerable downward adjustment of this figure.

The long-term impact on the environment of removing riparian vegetation is imperfectly understood. More information is needed on the effects which clearing riparian vegetation may have on food chains including soil microorganisms and insect populations. The most serious impact is probably the loss in wildlife and fish habitat. Where endangered species are involved, the loss may be irreversible. The treatments may change ecological relationships on floodplains, but there is little published information available at the present time on this subject.

Runoff water, fish, and wildlife may be contaminated when herbicides are used to control phreatophytes. Research on the hazards of herbicide contamination has been conducted for the most part on forested watersheds. In the more arid environments of Arizona's floodplains where chemicals might be applied annually for control purposes, the possibility of contamination may be higher than in humid forested regions. Higher herbicide application rates are used on riparian vegetation over more extended periods of time than in forested regions. In addition, the lower rainfall and lower population of soil microorganisms of desert areas as compared to humid forested regions might not be as effective in reducing herbicide residues. In areas of intensive agriculture there has been a reluctance to use chemicals, particularly aerial sprays, because lawsuits have been brought against agencies in the past for crop damage.

Social-Economic-Institutional Constraints

Economic data are insufficient to complete benefit-cost studies for mechanical, mechanical-chemical, and planted grass conversion treatments. Costs of mechanical and chemical treatments are available; however, little economic data pertaining to other resource outputs or losses associated with such treatments have been obtained. In addition, effects of clearing on wildlife, recreation and

aesthetics are difficult to quantify. For these reasons, a tabular summary of resource outputs and inputs was compiled. The possible loss or gain in resource outputs are given in physical units for a hypothetical 5,000 acre treatment in Table 14. Annual equivalent costs of treatment inputs for the low and high costs derived from the literature are listed in Table 13. Treatment costs were brought up to April, 1974 costs by use of the wholesale price index (U. S. Department of Commerce, Bureau of the Census 1974). The life of the projects was assumed to be 50 years and the discount rate eight per cent. Eight per cent was chosen because most economists recommended interest rates of between seven and 12 per cent as being appropriate for 1968 during hearings before the Subcommittee on Economy in Government of the Joint Economic Committee, U. S. Congress, according to Gregory (1972).

Table 14 indicates that the annual cost of a 5,000 acre mechanical treatment program would range between 23,000 and 138,000 dollars. Comparable values for mechanical with chemical control, and mechanical with planted grass conversion projects are 57,770 to 148,325 dollars and 25,220 to 155,685 dollars, respectively. In all three cases, over 65 per cent of the annual equivalent costs are attributable to annual maintenance necessary to prevent re-establishment of riparian vegetation. These data indicate that if two acre-feet of water per acre can be obtained annually for 50 years

Table 14. Physical gain or loss of resource products resulting from mechanical or chemical conversion treatments in riparian zones.

Resource Outputs	Physical Gain or Loss
Water	Under the most favorable conditions water yields of up to 2.5 acre-feet per acre annually may be obtained. However, some of this water will be used by reinvading vegetation.
Wood	At this time, riparian species have little or no commercial value except for cottonwood. However, fence posts, firewood, or chips for particle board and mulch are potential products.
Range	Areas which have shallow water tables (five feet or less) and higher precipitation (ten inches-15 inches) may produce herbage following artificial seeding, but the amount of production has not been adequately determined. If grasses become established naturally, it will take about five years and they will consist of weeds and annuals.
Wildlife	The quality of habitat for fish and wildlife will probably decline, particularly for doves, small game species, songbirds, javelina, and migratory waterfowl. Bristow (1968) placed a value of $150 per acre on phreatophyte lands as a result of hunting days lost and the price which the State Game and Fish Dept. is paying per acre for phreatophyte land. Mitigation of these conflicts in use becomes more difficult as phreatophyte lands for fish and wildlife habitat decline in area.
Flood Prevention	Removal of riparian vegetation prevents blockage of streamflow and the subsequent spreading of flood flows on adjacent floodplains which are sometimes developed.

Table 14.--Continued

Resource Outputs	Physical Gain or Loss
Recreation & Aesthetics	The aesthetic value of the treatment area is lowered in the initial stages. However, cattle grazing on riverine grass land and a view of flowing water may be aesthetically superior to riparian vegetation for some observers.
Other	Erosion rates increase between the initial removal of riparian vegetation and the establishment of grasses.

by conversion, cost will range between 2.30 and 15.60 dollars per acre-foot. If only one acre-foot can be obtained from such a treatment, the costs would double to 4.60 and 31.20 dollars, respectively. These relatively low costs for water salvage warrant further investigation of conversion projects. On the other hand, the monetary equivalent of losses of fish and wildlife habitat, recreation potential, and aesthetic quality were not evaluated in this analysis because the economic worth of the factors is undetermined. Neither were possible benefits from increased herbage production or reduced flood hazards included.

In an attempt to quantify wildlife values, Maddox (1972) compared the dollar value of water salvaged by phreatophyte removal with the dollar value of replacing wildlife lost by phreatophyte removal on the San Carlos Indian Reservation. The value of an estimated 2,300 acre-feet per year of salvaged water from the 1,720-acre cleared test plot was reported to be 84,000 dollars if used to grow a high-cash crop like long-staple cotton. The cost of raising the number of whitewing and mourning doves on game farms required to maintain the bird populations in the study area at their preclearing levels was estimated at 99,000 dollars. According to Maddox (1972), a minimum of two years using water gained by phreatophyte removal to grow high-cash agricultural crops would be necessary to offset the cost of replacing a few species of wildlife lost

due to phreatophyte removal. This economic evaluation did not include the gross value to the economy of the area from growing cash crops with salvaged water, the cost of preventing reestablishment of phreatophytes in the cleared area, and the value of averting potential damage by flooding. Neither did it include the cost of replacing quail, rabbit, javelina, mule deer, and waterfowl, which inhabit riparian lands on the San Carlos Indian Reservation.

Another economic consideration is the effect of scale on costs of riparian conversion programs. Lack of explicit information in published literature on conversion programs makes it difficult to determine if economies of scale (effect on cost of changes in the size of a clearing project) are present.

Until recently, the primary goal of floodplain management was to control or eliminate undesirable phreatophytes for water salvage and flood control objectives. However, pressure by environmental groups and the general public to preserve these areas for wildlife, recreation, and aesthetic values coupled with the requirement for producing environmental impact statements has caused most of the planned treatment programs by federal agencies to be suspended. An exception involves the USDI Bureau of Indian Affairs which is presently converting 33,000 acres of riparian land on the Colorado Indian Reservation to cropland

and may eventually clear as many as 65,000 acres (Le Crone 1973).

The USDA Forest Service and the USDI Geological Survey conducted research in mountain riparian zones to determine the feasibility of increasing water yields by manipulating the vegetation. However, the USDA Forest Service has no plans in the immediate future to treat riparian land on an operational scale for purposes of increasing water yields (Proctor 1973). A recent survey indicated that about 5,000 acres of USDA Forest Service land in Arizona can be classified as riparian vegetation, an amount considered insignificant for treatment to increase water yields according to Proctor (1973). The unresolved controversy concerning proper management of mountain riparian zones caused by conflicts in uses and competition for resources between recreation, wildlife and fish, and water interests is another reason the USDA Forest Service is not treating riparian zones for increased water yields.

Use of chemicals in eradicating phreatophytes is looked upon with some suspicion and disfavor by elements of the public. The possibility of damage to crops in adjoining areas of floodplains creates an additional constraint for use of herbicides in controlling phreatophytes.

Ownership patterns on riparian land could complicate proposed treatment programs because land management objectives vary between agencies and other land owners. The exact proportion of riparian or floodplain areas in public and private ownership is not known except along the Colorado River. If conversion projects are undertaken in the future, riparian areas which are privately owned may not be available for treatment.

A growing trend toward multipurpose management of floodplains rather than single-purpose management has developed in Arizona. Thus, conversion of riparian floodplain vegetation to grass or cropland may not be feasible in the future. Clearing by blocks or strips may be a possible compromise, but effects of this treatment on water yields and other resources such as wildlife, recreation, and aesthetics are not well known at the present.

CHANNELIZATION

Channelization methods are designed to remove the water supply from riparian vegetation. This approach involves either excavating a relatively narrow, deep conveyance channel, lining the channel with impervious material, or erecting levees along the sides of the channel. The first technique lowers the water table, thus reducing the transpiration rate of remaining floodplain riparian vegetation. It also reduces water surface area, prevents natural meandering of the river channel, and eliminates evaporation from standing water in shallow impressions along the river channel after high flows. The second two methods, lined channels and dikes, permit water to be routed efficiently through dense areas of phreatophytes without being spread onto the floodplain where the water may be disposed of by evapotranspiration, or where it may create favorable conditions for establishment of more riparian vegetation. Removal of riparian vegetation within the channel represents a significant proportion of reduced transpiration losses resulting from channelization. Channelization also serves as a flood control measure by containing runoff within the channel during periods of peak flows.

While the initial cost of channelization may be more expensive than other methods, such as mechanical or chemical

clearing, retreatment costs are less, as only the channel proper must be kept clear of reinvading phreatophytes. In the case of lined channels, no retreatment is necessary.

Justification for Water Yield Improvement

In floodplain areas where the water table is close to the surface, lowering the ground water level may reduce the amount of water transpired by phreatophytes and evaporated from the soil. Ground water pumping for agricultural, municipal, and industrial use had lowered water tables along some floodplain reaches in Arizona. Density of saltcedar communities in the affected areas has declined because ground water apparently is no longer within reach of their root systems. Horton and Campbell (1974) reported that in the Phoenix area, where in the 1940's a dense stand of saltcedar extended along the Salt River from east of Mesa through Tempe and Phoenix to the junction of the Gila River, saltcedar is now growing only as widely spaced desert-type plants. These observations are supported by experimental studies. Van Hylckama (1970) reported decreased water losses in tanks planted to tamarisk as depth to the water table increased. The annual water used by saltcedar for water depths of 5, 7, and 9 feet was approximately 8.0, 4.6, and 3.3 feet, respectively. Other investigators (Gatewood et al. 1950, Blaney 1933, Mace 1968) have reported a similar relationship showing decreased water loss with

increasing depths to ground water for various phreatophyte species. Ford (1958) used data obtained by Gatewood et al. (1950) to derive a multiple regression equation to predict the draft on ground water in the Gila River floodplain from Thatcher to Glenbar, Arizona. The variables included air temperature, precipitation, and depth to ground water. Analysis indicated that with a five foot lowering of the water table, a water savings of about 27,000 acre-feet annually could be realized. In addition, Hughes and McDonald (1966) and Robinson (1970) reported significant decreases in evaporation from bare soil tanks as depth to ground water increased.

Results of the Bernardo tank studies in New Mexico differ from the above results because no relationship between water use and depth to water table was discovered. Tamarisk plants recovered in one year when the water table was lowered 3.4 feet in some of the Bernardo tanks. This information implies that for channelization to successfully limit transpiration of tamarisk, the water table would have to be lowered by more than 3.4 feet. Other conditions which might affect growth of saltcedar root systems and their rate of recovery from a drop in the water table, would be stage of growth, rate at which the water table drops, and amount of annual precipitation.

After the Hoover, Davis, Parker, and Imperial Dams were built on the Colorado River, the flow was regulated, but

the river channel remained unstable. Reaches of the river below the dams were scoured and deepened, whereas other reaches were raised by extensive sediment deposits. Authority under the Colorado River Front Work and Levee System Act of 1927 was expanded in 1946 to permit the USDI Bureau of Reclamation to initiate an active Colorado River Operation and Maintenance Program (USDI Bureau of Reclamation 1969). Channelization by dredging was initiated to prevent flooding and destruction of lands resulting from a meandering river and deposition of sediment in the river channel. Water salvage by channelization was also incorporated into goals of the channelization project. According to the USDI Bureau of Reclamation (1964), additional benefits to be derived from channelization include:

1. The reduction of erosion and transported sediment, thereby stabilizing stream conditions and improving water quality.
2. Improved efficiency of water deliveries to downstream users.
3. Decrease of flood hazard to certain improved areas.
4. Improved drainage benefits to certain lands that have ground water levels near the ground surface.
5. Protection of developed lands adjacent to the river channel.

Upon completion, the project will reduce sediment yields by an estimated 1,820,000 tons per year and salvage an

estimated 191,300 acre-feet of water per year (USDI Bureau of Reclamation 1964).

The methods used to determine these estimates were not described and therefore it is difficult to ascertain their accuracy. Problems of determining the rate of evapotranspiration accurately from bottomland vegetation were pointed out in the hydrology section above. The difficulty of determining vaporization rates from plant, soil, and water surfaces would apply to the Colorado River area as well as other localities. Therefore, the estimate of water salvage should be considered only as an approximation and possibly subject to large error. Similarly, the estimate of sediment reduction should be considered only as an approximation due to possible sampling or measurement errors on a river as large as the Colorado.

The U. S. Army Corps of Engineers has been planning flood control projects on the Gila and Salt Rivers in Arizona since 1958. These projects include provisions for levees, phreatophyte clearing and low flow channels along various stretches of the Gila and Salt Rivers. A 2,000-foot-wide cleared floodway, 43 river miles in length and a low-flow channel 1.7 river miles in length are planned for the Salt River. And on the Gila River near Phoenix, a 2,000-foot-wide cleared floodway, 34 river miles in length and a low flow channel, 28 river miles in length, are planned. These channel improvements would result in an

estimated net annual increase of 16,000 acre-feet of water available for agriculture (U. S. Army Corps of Engineers, South Pacific Division 1969).

Clearing of 94 miles on the Middle Gila River floodway from the upper end of Safford Valley to the Buttes Reservoir site may result in an estimated net annual increase of 19,800 acre-feet of water (U. S. Army Corps of Engineers, South Pacific Division 1969). Also reported in this publication were plans for constructing 50 miles of compacted-earthfill levees on the Lower Gila River from Painted Rock Reservoir to the Gila siphon about ten miles east of Yuma. No estimate of water salvage was given.

Hydrologic Response to Water Yield Improvement

Channelization and floodway clearing through dense phreatophyte growth on a 35-mile stretch of the Rio Grande River above Elephant Butte Reservoir in New Mexico salvaged an estimated 200,000 acre-feet of water (method of estimation not disclosed) from 1951-1956 (Timmons 1959). Future annual water savings (time period not expressed) were estimated at 45,000 acre-feet. Fletcher and Elmendorf (1955) described this section of the Rio Grande Valley as having a heavy growth of cottonwoods, willows, and salt-cedar with almost no channel existing for considerable distances. The poorly developed channel and dense vegetation resulted in much of the river discharge being

dissipated without reaching the reservoir. The low water channel caused the water table to decline by eight to ten feet on the average, and water flowed into Elephant Butte Reservoir which had formerly failed to flow through the 35-mile section. Thompson and Elliott (1957) reported that on another 40-mile reach of the Rio Grande River annual water savings amounted to 40,000 acre-feet of water (method of estimation not disclosed) as a result of channeling. A proposal for construction of a network of side drains, affecting about 5,000 acres, would save an estimated 8,000 acre-feet of additional water annually.

The 280-mile Lower Colorado River has been undergoing channelization by dredging since 1948 by the USDI Bureau of Reclamation. The total river improvement program by the USDI Bureau of Reclamation may eventually result in an estimated annual recovery of some 190,000 acre-feet of water currently disposed of by evaporation and transpiration from the 240 miles of river between Davis Dam and the border of Mexico (Oliver 1965).

Influence on Other Natural Resources

Timber

Although riparian species have little commercial value, channelization methods remove only vegetation growing in the channel; thus, potential wood products would still be available on adjacent acres. However, riparian vegetation

growing along the channel and on the floodplain may decrease in density due to a lower water table following channelization.

Herbage

Since the vegetation is left undisturbed on the floodplain, the only possible increase in herbage production would be from grasses which might invade the channel. If the water table is lowered significantly by channelization, whatever grasses might exist near the channel and on the floodplain would possibly die off or decrease in density due to a lack of available water. Furthermore, grazing probably would not be feasible along or in the channel.

Wildlife and Fish

The channelization process confines the natural river to a deep, narrow, often rock-lined canal and is therefore detrimental to the fish and wildlife resource (Arizona Game and Fish Department 1971). Recent studies in Idaho, Montana and South Carolina indicate that 80 to 90 per cent of the fishery resource may be lost from this type project. Except in a few cases, the adjacent marsh and backwater habitat is also destroyed when it becomes filled with dredge spoil or is drained by the channelization process.

However, Jonez (1968) stated that when dredging realinement on the Colorado River leaves a large oxbow lake

or pond, inlet and outlet structures are provided to permit a flow of fresh water through the bypassed river channel. The structures often include gates to regulate the water level for wildlife management purposes. Culverts have been installed, for the benefit of fish and wildlife, to circulate water to backwater areas which become isolated by embankment training structures. These structures and construction roads have provided increased access for fishermen to the lower Colorado River.

The Yuma clapper rail, subspecies of the more common ocean marsh clapper rail, nests on the Colorado and is recognized as an endangered species (Lower Colorado Region Comprehensive Framework Study Appendix VIII 1971). This marsh bird is the only such rail which lives in fresh water marshes of the United States (Todd 1970). Cattails, an important part of its habitat, are often removed by channelization. Other birds which nest in Colorado River marshes are the least bittern (Ixobrychus exilis Gmel.), black-crowned night heron (Nycticorax naevius Bodd.), snowy egret (Garzetta candidissima Gmel.), piedbill grebe (Podilymbus podiceps Linn.), and black-necked stilt (Himantopus mexicanus Mull.). These birds may also be affected when adjacent wetlands are drained in the channelization process.

Several studies have shown that marshes are among the world's most productive habitat for both variety and

number of birds according to Todd (1970). Only salt water estuaries are rated higher.

Cement lined channels can be detrimental to wildlife, especially deer. The Wellton-Mohawk canal which runs through the Mohawk Valley east of Yuma is an example. During November and December of 1968, at least 25 drowned deer, ranging from fawns to four-point bucks, were taken out of this canal (Furlow 1969). A number of live deer have also been rescued. To correct this problem, irrigation district officials and the game and fish department designed cement escape stairways placed just in front of the check gates along the canal. A pipe is also placed across the canal at an angle to guide weary animals toward the stairs and keep them from entering the gates.

An environmental impact study was prepared for the U. S. Army Corps of Engineers Lower Gila River Project, by The University of Arizona, School of Earth Sciences, Office of Arid Land Studies (1970). The report evaluated the "environmental impact" of the original authorized plan which called for clearing a 750-foot wide floodway for 50 river miles and construction of 18-foot high levees with two ten-foot wide strips of vegetation permitted to regrow inside the levees. Seven variations of this plan were also considered, and included variations in the width of the floodway, height of levees, and widths of undisturbed vegetation. According to this study, the proposed project

would result in the reduction of wildlife habitat, particularly game bird habitat consisting of cattail marshes and saltcedar-arrowweed thickets. The report also indicated that the extent of detrimental impact would be reduced by the proportion of relatively undisturbed floodplain biological communities such as cattail marshes and saltcedar-arrowweed thickets lying outside of the clearing right-of-way because this area would not be destroyed in the channelization process. Based on a hypothetical 1,000-foot right-of-way, 64 per cent of the saltcedar-mesquite communities, 56 per cent of the open water, and 57 per cent of the cattail marsh would lie outside of the right-of-way. However, 8,000 acres of non-allocated state and federal land in the channel area, much of it irrigable, could be sold and developed when the flood control program is consummated. This might be to the detriment of wildlife, since there may be a tendency for farmers to occupy all land outside the levees, thus reducing wildlife habitat. Such loss of wildlife habitat possibly could be avoided if the land now occupied by phreatophytes outside of the right-of-way were set aside for wildlife use by joint action of agencies and other interested individuals.

The report also stated that the greatest unfavorable impact will be to native flora and fauna of which the whitewing dove is considered to be most important because of the great numbers nesting in saltcedar thickets. The

importance of this habitat has increased in recent years because of the reduction of suitable habitats elsewhere in Arizona.

With proper planning and interagency cooperation, fish and wildlife habitat may not necessarily be entirely destroyed and, in some cases may be enhanced. Interagency cooperation was demonstrated in 1968 when the USDI Bureau of Reclamation altered channel networks to an isolated backwater area created during the 1964 channelization of the Colorado River near Blythe, California. In response to a proposal by the Arizona Game and Fish Department, dredges were used to deepen channels leading to this oxbow, thus improving water circulation and preserving waterfowl habitat.

Recreation and Aesthetics

Large privately owned recreation-oriented developments are located along the Lower Colorado River between Bullhead City, Arizona, and Needles, California. According to Jonez (1968), most of these developments would not have been possible without the river management and stabilization work being carried out by the USDI Bureau of Reclamation. Another benefit to recreation often cited is the increased access into treated areas for fishermen, hunters, and dune buggy enthusiasts created during channelization projects.

Channelization affects the aesthetic quality of riparian zones by the impact of channelization itself, and by the secondary effects on phreatophyte vegetation along the river and associated floodplain.

Channelization, perhaps to a greater extent than levee construction, destroys the natural character of a river. Meanders may be eliminated because linear dredging is most economical and efficient. Concrete-lined channels, riprap on banks, and dredge spoil deposits along the edges of the channel contribute to the creation of an "unnatural" landscape feature. If the spoil banks are not revegetated, the result may be the creation of a relatively barren watercourse with little aesthetic quality.

Channelization might have the effect of lowering the water table in the vicinity of the river, particularly if the channel were lined, and would also prevent the spread of surface flood water to phreatophytes growing on the floodplain. As a result, new seedling establishment would be inhibited, young saltcedar would possibly be eliminated, and only the hardier mature trees with enough root vigor to follow the declining water table would survive. The resulting reduction in density and inhibition of the spread of saltcedar may provide an aesthetic benefit. However, channelization may also cause marshes and oxbow lakes along the watercourse to dry up, a development that could be considered adverse from an aesthetic point-of-view.

Irrigation of selected portions of the floodplain might preserve the more important and scenic of these features, particularly those with valuable wildlife and visual qualities.

While channelization provides an example of the construction of the functional landscape, it is difficult to conclude that such a treatment enhances the quality of the visual landscape, especially in the immediate vicinity of the watercourse. However, possibly some form of non-linear channelization together with careful attention to spoil bank revegetation, and the preservation of scenic oxbow lakes and marshes through selective irrigation may result in a landscape with enhanced aesthetic qualities.

The construction of levees to control phreatophytes and enhance water supplies would result in two general visual changes. The first impact would result from the construction process and the appearance of the levees. A second consideration would be the long-term effect of the levees on the phreatophyte vegetation along the channel and on the associated floodplain which had not been affected by the actual construction process itself.

Levee construction designed to contain flooding and prevent loss of water would introduce an unnatural feature into the river landscape. Seen from above, the levees would tend to diminish the natural characteristics of the river channel; the result would be a heightened linear impact. If

sufficient phreatophyte vegetation were retained along the channel and in the floodplain outside of the levees, low structures would probably not be apparent to the casual observer at ground level unless he were close to the construction.

Possibly the effects of the construction of the levees would have a greater adverse visual impact than those resulting from the unaesthetic qualities of the structures themselves. Levees eighteen feet high would involve some massive earth-moving with significant vegetative destruction and soil scarification. These impacts would diminish with time, but several years may be required before the reestablishment of vegetation on affected areas would take place, particularly in the arid Southwest.

Levee construction will possibly have a long term influence on the floodplain vegetation when it can no longer obtain moisture from the river. A drying effect may result, and phreatophyte vegetation may no longer have access to the surface moisture previously delivered to the plants by floods. Phreatophytes with taproots already in contact with the water table may not be disturbed, but younger plants and seedling germination and establishment success may be adversely affected. The result might be the death of some of the younger saltcedar, the elimination of the spread of the phreatophytes to new areas, and some reduction in the density of the surviving vegetation.

Aesthetically, these consequences may tend to enhance the attractiveness of the landscape in some situations. However, cattails and other marshy vegetation dependent on standing water would be eliminated, and this may cause a loss of scenic and associated wildlife qualities. A solution might be to preserve certain valuable marshes through the irrigation of selected areas on the floodplain outside of the levee boundaries.

In sum, it would appear that levee construction offers the potential for both negative and positive aesthetic impacts upon the riverine landscape. It has been suggested that the "functional landscape" can be interesting and attractive if it enlightens the observer with regard to the management opportunities of the land. It would appear that landscaped levees might serve this educational purpose, particularly when viewed from an elevated vantage point. Unfortunately, the opportunities for this sort of observation are limited, and at ground level the function of the levees, especially when viewed at close range, ordinarily would not be readily apparent.

Other

By widening and straightening stream channels, the conveyance capacity of rivers may be increased. However, the rates of floodflows at the downstream end of valleys or

at the terminus of channelization treatment areas may be increased (Burkam 1973).

Changes in bottom land vegetation between December 1965 and August 1967 apparently caused significant differences in the mean cross-sectional velocity, mean cross-sectional depth, and boundary roughness at peak discharges of two major floods in an 11.5-mile study reach of the Gila River near Safford, Arizona (Burkam 1973). The first flood which had a peak flow of 39,000 cubic feet per second (c.f.s.) occurred in December 1965 when the dense bottom land vegetation was dormant. The second flood, which had a peak discharge of 40,000 c.f.s. occurred in August, 1967, when the vegetation had been eradicated in the upstream half of the study reach five months prior to this flood. Compared to the first flood, large amounts of foliage in the uncleared half of the reach during the second flood apparently caused a five per cent decrease in mean velocity, a six per cent increase in mean depth, and an 11 per cent increase in the Manning roughness coefficient at peak stage. In the cleared part of the study reach, there apparently was a 30 per cent increase in mean velocity, a 13 per cent decrease in mean depth, and a 30 per cent decrease in Manning roughness coefficient at peak stage.

The mean velocities of both peak flows were relatively low in the segments of the study area where large parts of the flows moved across the meandering stream

channel; the Manning coefficients were relatively large in these segments.

The data presented above indicate that when phreatophytes are cleared from stream reaches which have vegetative and hydrologic characteristics similar to the Gila River near Safford, Arizona, the depth of flood flows may be decreased but the velocity is increased. For purposes of flood control the decreased depth of flood waters may be important where valuable property or structures are located adjacent to cleared areas on the floodplain. However, the increased velocity of flood flows after phreatophytes are cleared may be potentially more destructive than the greater depth of flood flows and slower velocities before clearing. Jahn and Trefethen (1972) reported that channelization only modifies the pattern of flooding and can only satisfy its fundamental function of flood control on limited areas. Accelerating the flow of water from the land in the vicinity of the excavation is the hydrologic principle behind channelization as a flood control tool. Unless the channel mouth empties directly into the sea or other large body of water, the flood waters and silt may contribute to flooding and sedimentation on unchanneled segments downstream (Jahn and Trefethen 1972).

Economic Considerations

Direct Returns to the Land

Channelization projects may result in substantial water savings. Channelization of two 35- to 40-mile stretches of the Rio Grande River in New Mexico resulted in an estimated annual water savings of about 40,000 acre-feet on each reach (Timmons and Klingman 1960). At a price of ten dollars per acre-foot (U. S. Army Corps of Engineers, South Pacific Division 1969), this would yield an annual return of 400,000 dollars.

The U. S. Army Corps of Engineers, South Pacific Division (1969) estimated that the clearing of phreatophyte growth from floodways on the Gila and Salt Rivers near Phoenix, Arizona, will result in a net increase of 16,000 acre-feet with an estimated annual value of 160,000 dollars in 1968. The middle Gila River channel clearing from the upper end of Safford Valley to Buttes Reservoir site (94 miles) was estimated by the U. S. Army Corps of Engineers to yield a net annual increase of 19,800 acre-feet of water worth 1,104,000 dollars for agricultural production.

Rechanneling 30 miles of the Colorado River near Needles, California, resulted in an estimated 60,000 acre-feet of water salvage per year, and the total river improvement program was estimated to recover annually some 190,000 acre-feet of water, according to Oliver (1965). The

channelization also reduced erosion and sediment which were detrimental to downstream irrigation facilities.

Channelization, stream realignment, and levees prevent flood damages and reduce the amount of water used by riparian vegetation. The economic benefit depends on the value of adjoining lands. It is highest in municipal and residential areas, decreases in agricultural areas and is lowest in uninhabited desert areas. The Gila and Salt Rivers levee and channel improvement project near Phoenix, Arizona would prevent damages estimated at about 7,000,000 dollars in 1968 if the standard project flood should occur, according to the U. S. Army Corps of Engineers, South Pacific Division (1969). In addition, the Lower and Middle Gila River Channel Improvements Projects would prevent damages estimated at 23,500,000 dollars and 474,000 dollars in 1968, respectively, if a project design flood should occur (U. S. Army Corps of Engineers, South Pacific Division 1969).

Direct Costs of Implementation

The cost of channeling 35 miles of the Rio Grande River in 1951 was placed at 1,463,000 dollars (Timmons and Klingman 1960). No estimate was given for the annual cost of maintaining the channel. However, based on other reports, the costs would possibly range between five and ten dollars per acre depending on the method used (Lowry 1966).

The cost of the Gila and Salt Rivers levee and channel improvement project was estimated at 3,860,000 dollars in 1964 (U. S. Army Corps of Engineers, South Pacific Division 1969). The costs of the Lower Gila River and Middle Gila River Projects were estimated at 31,300,000 dollars and 2,000,000 dollars, respectively. No estimates of maintenance or retreatment costs were given, but would possibly be about five to ten dollars per acre (Lowry 1966).

The estimated total cost for the complete channelization plan on the Lower Colorado River excluding the completed Mohave Valley Division construction was about 36,425,000 dollars (USDI Bureau of Reclamation 1964).

Opportunity Costs

Channelization can have a detrimental effect on the wildlife resource. However, by building culverts to circulate water into backwater areas, the situation may be ameliorated.

Since the vegetation is left in a more undisturbed state than the other treatments, recreation, and aesthetics may also be relatively unaffected. However, flooding and sediment production may be increased downstream from the channelized segments.

Extent of Current Implementation

Portions of the Colorado River from Davis Dam to the Mexican border have been channelized by the USDI Bureau of

Reclamation over a period of many years. Approximately 44 miles of the 280-mile reach have been realined by dredging and another 37 miles have been stabilized by embankment training structures or dressed banks.

Approximately 178 miles of the Gila River and 43 miles of the Salt River have been authorized for channel improvements by the U. S. Army Corps of Engineers, but are still in the planning stages. These projects have been suspended pending the outcome of litigation by environmental groups, or approval of environmental impact statements.

Potential for Future Implementation

Vegetative-Physiographic-Climatic Constraints

The physical factors discussed in the conversion section which influence the amount of water transpired by riparian vegetation are also important when considering channelization treatments for water salvage. The depth to ground water on the floodplain before and after treatment is a key factor in channelization programs to reduce water use by riparian vegetation. If the water table is shallow (four feet or less) a channelization program probably would not be effective because it may make conditions more favorable for growth of saltcedar. Channelization would also be of little apparent use in areas where the water table is already 20 feet deep or more and supporting a

sparse riparian growth. Even in those areas where the water table is at an optimum depth for most phreatophytes (five to ten feet deep) prior to channelization, the effect of lowering the water table on evapotranspiration is imperfectly known. While some tank studies have shown that water use by riparian species tends to decrease as depth to the water table increases, the Bernardo tank studies in New Mexico did not. When the water table was lowered 3.4 feet in two tanks for one growing season, tamarisk was able to recover in one year. The following year the tamarisk plants used nearly the same amount of water at the deeper depth as they had used at the shallower water table depth the previous year.

Channelization, by routing water efficiently through dense riparian vegetation and preventing it from spreading out onto the adjacent floodplain during periods of high flow, reduces the amount of water transpired by plants and evaporated from soil surfaces.

The site of channelization is particularly important. The best location for such projects would be in areas which require water for agriculture, municipal, or industrial uses and protection from flooding. Another important consideration involves the downstream end of channelization projects. If channelization terminates at a reservoir no problem exists, but in other cases the problems of riparian plant

water use and flooding may just be translated downstream following channelization.

The impact of channelization on wildlife may not be as severe as it is with mechanical and chemical clearing because not as much vegetation is removed. However, channelization can be detrimental to fish and waterfowl when marsh areas and sloughs dry up because of a drop in the water table. If the water table is permanently lowered, many of the effects on fish and wildlife may be non-reversible, especially for endangered species.

Social-Economic-Institutional Constraints

Environmental groups have attempted to halt channelization projects in Arizona by legal means. For example, the Sierra Club and others obtained a court injunction which temporarily prevented the U. S. Army Corps of Engineers from constructing 94 miles of channel improvements on the Middle Gila River from the upper end of Safford Valley to the Buttes Dam site because no environmental impact statement was written in accordance with the National Environmental Protection Act. As a result of the court injunction, an impact statement was written and submitted to the Council of Environmental Quality. According to the U. S. Army Corps of Engineers (1973) the Middle Gila River project is still in litigation.

On the other hand, water interests such as farmers and irrigation districts often favor projects which might provide more water for agriculture or protect their lands from flooding. Channelization projects are particularly popular with water interests because in many instances no reimbursements to the federal government are required, in contrast to other types of water developments. Reimbursements are not required because it is not possible to accurately identify the individual organizations directly benefitting from the water salvaged by the channel improvement program, or to determine the amount of water received, or the benefits resulting from the use of the salvaged water (U. S. Army Corps of Engineers 1961).

Table 15 illustrates the economics involved for three channelization projects authorized for the State of Arizona, but which have not yet been started for various reasons (U. S. Army Corps of Engineers 1973). The cost of the projects, and the estimated flood damage (dollar value) prevented if a project design flood should occur, were increased to equivalent April, 1974 costs to account for inflation, using the wholesale price index for all commodities (U. S. Department of Commerce, Bureau of the Census 1974). The annual equivalent costs were computed based on a 50-year project life and an eight per cent interest rate. It appears that most channelization projects are perhaps more justified for flood protection than for

increasing water yields (Table 15). The predicted water salvage from the Gila and Salt River Levee and Channel Improvement Project is no longer valid because ground water pumping in that area for agriculture has already lowered the water table, and consequently saltcedar thickets have been reduced to a scattering of brushy clumps.

The Middle Gila River Channel Improvements Project has a favorable cost/benefit ratio (Worthington 1973). On the other hand, a second study of the Lower Gila River Levee and Channel Improvement Project made recently by the U. S. Army Corps of Engineers showed a major reduction in benefits. The change in benefits was caused by two factors Worthington 1973). First, the cost of construction had increased faster than the value of additional agricultural products which could be produced with additional water provided by the project. Secondly, reevaluation indicated that occurrence of the standard project flood was once in 1,000 years rather than once in 150 years as estimated in the original study.

It seems possible that the three authorized channelization projects will not be constructed either because of low benefit/cost ratios or because of public pressure to retain the riparian environment in a relatively "natural" state.

In a recent development, the Wellton-Mohawk Irrigation and Drainage District bulldozed the riparian vegetation

from a 200-foot wide strip along 40 miles of the Lower Gila River (Arizona Daily Star 1973). Farmers were given permission by the Yuma County Board of Supervisors to bulldoze brush from the river to stop flooding in the area. The channelization traversed 41 acres of a Game and Fish Commission wildlife area and a large amount of federal land recognized as important wildlife habitat. The Arizona Game and Fish Commission filed a suit against the irrigation district for unauthorized digging in the river channel. At the court hearing the judge ordered the Wellton-Mohawk Irrigation and Drainage District and the Arizona Game and Fish Commission to reach an equitable solution acceptable to both parties out of court. To date, no agreeable solution has been reached (Bristow 1975).

COTTONWOOD THINNING

The cottonwood thinning method consists of a selective thinning of cottonwood groves and eradication of saltcedar and willows when present. Generally, 50 to 90 per cent of the cottonwood trees are removed (Anonymous 1969). Increased light penetration, which occurs after thinning, allows bermuda grasses to invade areas where cottonwoods have been removed. Areas for potential treatment include the Verde, Little Colorado, and Gila River drainages which have major concentration of cottonwood stands.

Justification for Water Yield Improvement

The treatment is designed primarily to reduce evapotranspiration and flood hazards. During periods of peak flows, dense cottonwood groves collect brush, trash, and logs. These debris dams may divert water from the natural channel or cause it to spread over the floodplain. In addition, as water washes around the sides of debris dams, scouring with associated sediment production can occur. After thinning, the cottonwood trees no longer form a matrix on which large driftwood dams may be formed. Additional benefits include increased herbage production and a more pleasing area for recreation.

Hydrologic Response to Water Yield Improvement

The Salt River Project cooperative cottonwood control program on the Verde River and Oak Creek, where 1,029 acres have been treated, has not produced information on water yield increases. A series of springs along the Verde River and irregular return flows of irrigation water prevented accurate stream gaging in the treated areas. However, according to Warskow (1968), yields from the Verde Valley treatments are estimated to be two acre-feet per acre per treated year, based on research results from the U. S. Geological Survey's Cottonwood Wash Study (Hendricks, Kam, and Bowie 1960). According to Warskow (1973), indications of increased water yield were found after treatment. Water had accumulated in the bottom of gravel pits near the stream, and for the first time that many Verde Valley residents could remember, water was in sufficient supply to meet all the water users' needs in the Verde Valley without rationing. The estimate of increased water yield may be adequate immediately after the thinning treatment, but as cottonwood canopies close, root systems penetrate thinned areas, and grasses become established, water yield increases would possibly decline below the original two acre-feet per acre estimate.

Influence on Other Natural Resources

Timber

Barger and Ffolliott (1971) reviewed the prospects for cottonwood utilization in Arizona. Cottonwood occupies approximately 6,000 to 8,000 acres in the state (Figure 2) with major concentrations in the Verde, Little Colorado, and Gila drainages. Pulpwood and box and pallet manufacturers are the two most promising users for cottonwood in the state. However, lack of established markets for timber products and the limited and uncertain supply of cottonwood timber restrict its utilization in Arizona at the present time.

Cottonwood timber can best be utilized by phasing it in with other species in existing utilization operations. Utilization as pulpwood, where the pulping operation is large enough to be relatively unaffected by fluctuations in cottonwood supply, appears to be the most feasible practice at present.

Herbage

The majority of the initial treatment areas in the Verde Valley have completely sodded over with bermuda grass and are being used by domestic livestock (Anonymous 1969). Increases in herbage in terms of pounds per acre or increased carrying capacities in terms of animal unit months have not been estimated.

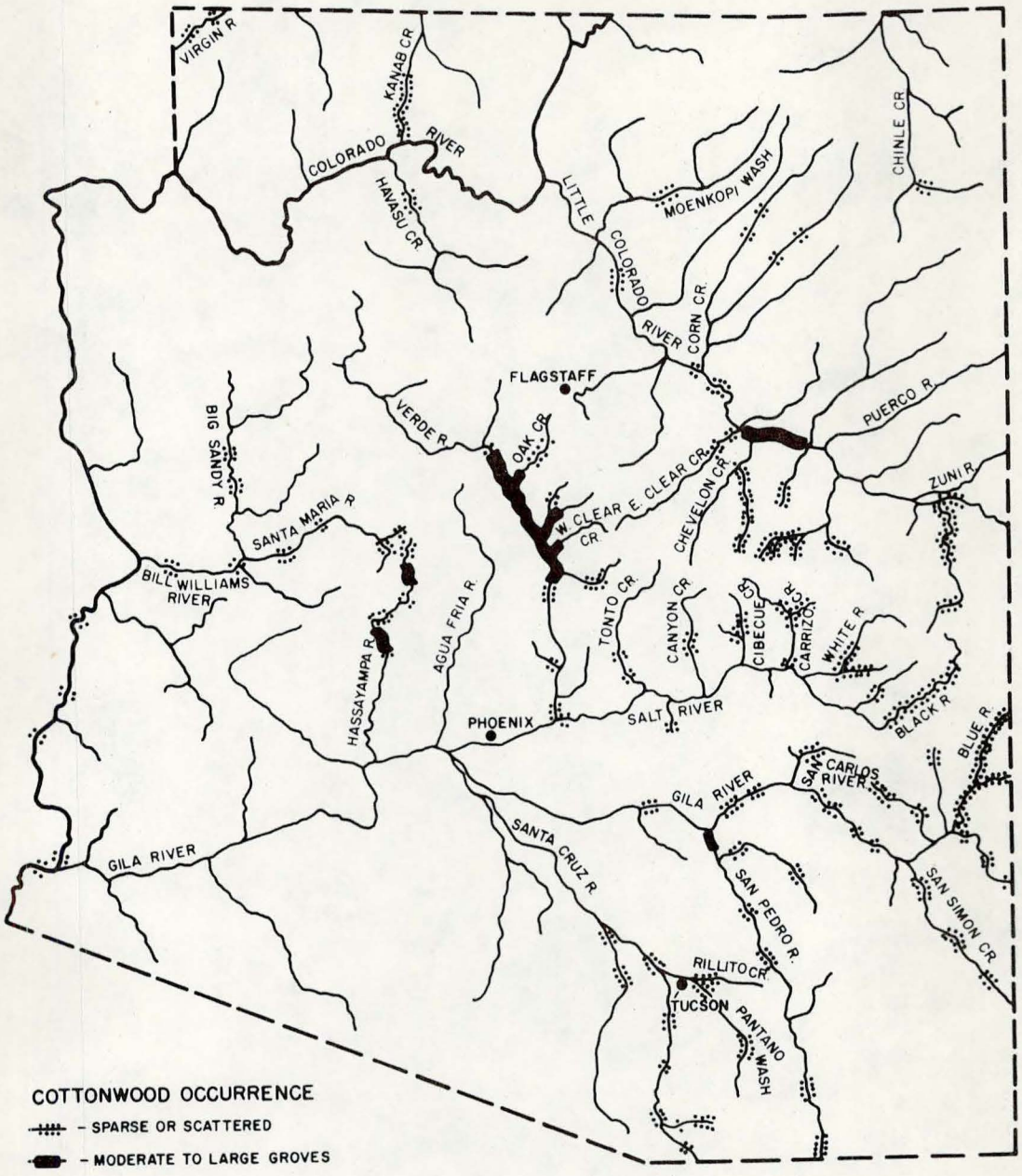

Figure 2. Estimated distribution of cottonwood species in Arizona -- The distribution shown is a composite of estimates obtained from 11 federal and state agencies, based upon their knowledge and experience in various sections of the state (Barger and Ffolliott 1971).

Wildlife and Fish

In Arizona, higher elevation riparian communities along perennial streams provide cover for many species of wildlife. Riparian vegetation also benefits fish habitat. Deep-rooted vegetation along streams retards excessive erosion, and the shade of riparian canopies tends to keep stream temperatures comparatively low, thus limiting algae growths in still pools.

According to Stone (1971), fishery investigations show that clearance of cottonwoods along the Verde River, Oak Creek, and West Clear Creek has had a detrimental effect on the present fish habitat and has made establishment of a new fishery difficult. In cleared areas along these rivers, the survey (electro-fishing and gill nets) indicated that fish populations were reduced by approximately 90, 45, and 100 per cent, respectively. According to Stone (1971), reduced fish populations are probably the result of a reduction in habitat by the removal of bank cover and silting in of cleared areas of the river. Prior to clearing, root systems of the cottonwood trees stabilized soil on steep river banks and exposed roots in bank undercuts provided cover for fish. In addition, exposed roots obstructed stream flow and caused water to swirl and scour out holes creating deeper water for fish.

Since all clearing was completed prior to the beginning of this fish habitat study, changes in stream

physical characteristics as a result of cottonwood thinning were based on comparisons between cleared and uncleared stream reaches, a technique which may decrease the validity of the conclusions.

Studies of bird nesting densities in the same area indicate a possible loss of bird life as a result of clearing. A five-year research project was initiated in 1969 (Carothers and Johnson 1970) to observe effects of riparian manipulation, primarily cottonwood thinning on wildlife, in the Verde Valley using a breeding bird survey as an indicator. Study plots were located in "severely" thinned, "moderately" thinned, and "unmanipulated" (control) areas. Data for the first two years indicate a direct linear relationship between number of mature trees on an area and number of birds found there. The number of birds appeared to increase as the number of trees increased. On the severely thinned plot, which contained ten mature cottonwoods per acre, there were 582 pairs of nesting birds per 100 acres in 1969, and 524 pairs in 1970. On the moderately thinned plot, which contained 26 mature cottonwoods per acre, there were 963 and 886 pairs of nesting birds per 100 acres in 1969 and 1970, respectively. The control plot, which contained 47 trees per acre, had 1,324 pairs of birds per 100 acres in 1969 and 1,006 pairs in 1970. The study is designed to determine how riparian habitat in the Verde Valley can be managed without seriously

altering the breeding bird populations and their species diversity.

Todd (1970) reported that riparian vegetation at the lower elevations contains the widest variety and number of birds found in any natural habitat in Arizona, or of any inland habitat in western North America, and many of these birds would not be present without these riparian habitats. According to Todd (1970), many people enjoy seeing these birds and in knowing they are present. Todd also indicated that winter and summer out-of-state visitors travel to Arizona to see a variety of uncommon birds, and special trips are organized throughout the nation by groups for this purpose.

Cottonwood trees tend to be the staple food of the beaver in most of the lower river valleys (Todd 1970). Trees in the five- to ten-year-old class are usually preferred. Where these trees are thinned, beavers are forced to utilize whatever trees are left. In a thinned habitat, many of the remaining trees, even older more mature trees, may be killed by beavers.

Recreation and Aesthetics

Higher elevation riparian communities along perennial streams have a high recreation potential for hiking, picnicking, camping, and fishing in Arizona. Treated areas which are open to public access along the Verde River are

popular picnic and overnight camp sites (Anonymous 1969). Increasing population growth in the Southwest may cause increased demands for stream and floodplain resources for recreation purposes.

Considering the types of treatment available for control of phreatophyte vegetation in the Southwest, thinning of cottonwoods is perhaps the most aesthetically desirable. Unsightly debris dams may be prevented after dense linear cottonwood stands along mid-elevation watercourses are thinned. If the treatment is carefully conducted, the overstory may be opened to allow the development of a grassy ground cover while enough shade is retained to make the treated area desirable for picnicking, camping or fishing. With the density of streamside cottonwoods reduced, the river or stream becomes more visually accessible and the landscape may become correspondingly more heterogeneous and attractive.

Slash resulting from the thinning operation should be disposed of if possible, to enhance the aesthetic appearance and prevent debris dams from forming again. The slash could be burned or perhaps chipped. Thinning during the dormant season would produce less troublesome debris. Trees should be cut close to the ground to minimize the adverse impact of stumps.

Other

Cattle grazing in thinned treatment areas has apparently prevented regeneration of cottonwood seedlings (Johnson 1973). If grazing continues to prevent regeneration, the species composition along the Verde River may eventually be altered to other forms of vegetation which are less desirable than cottonwoods.

Economic Considerations

Direct Returns to the Land

Possible benefits accrued from cottonwood thinning include reduced evapotranspiration losses, reduced flood hazards, increased production of grass for livestock, and improved recreational opportunity. Monetary values for these benefits have not been reported.

Direct Costs of Implementation

Treatment costs for the Salt River Project's cooperative cottonwood control program have averaged 41 dollars per acre exclusive of disposal. The latest contract bid in 1969 was 52 dollars per acre (Moore 1969).

Opportunity Costs

The opportunity costs include the possible loss of fish and wildlife habitat and, in cases of severe thinning, a possible reduction in aesthetic value and perhaps increased erosion.

Extent of Current Implementation

Extensive thinning of cottonwoods has only been conducted in the Verde Valley where 1,029 acres were treated on Oak Creek and the Verde River. These treatments were accomplished by private contractual agreements between the Salt River Project and private landowners. The Salt River Project agreed to pay all costs of thinning and piling the trees. The landowners selected the trees to be thinned and disposed of the debris, usually by burning.

Potential for Future Implementation

Vegetative-Physiographic-Climatic Constraints

The potential for salvaging water along the higher elevation perennial streams is high when riparian communities are completely eradicated. Bowie and Kam (1968) reported almost a 50 per cent decrease in water use after riparian vegetation was eradicated along a 1.5 mile reach of Cottonwood Wash in Mohave County, Arizona. However, this information cannot be applied directly to cottonwood thinning treatments. Factors affecting evapotranspiration such as solar radiation, wind velocity, and relative humidity would possibly be different within thinned cottonwood stands as compared to the open clearcut areas at Cottonwood Wash. As cottonwood canopies reclose and root systems spread into thinned areas, evapotranspiration may

increase. However, the length of time it takes for thinned areas to return to their original density is not known. The amount of water diverted from channels by debris dams during floods and therefore unavailable to water users downstream is also unknown. Until the above factors are better understood, the potential for increasing water yield by thinning cottonwoods will remain unknown.

Social-Economic-Institutional Constraints

Some dissatisfaction with the Salt River Project cooperative cottonwood control program has been expressed. According to Horton (1969), this program caused a major controversy, and letters to the editors of Phoenix newspapers were almost a daily occurrence during the heat of the controversy. In most cases, the removal of trees was protested, even though a "large" number of trees were left standing for shading and recreational values.

The treatment cost for thinning cottonwoods on the Verde River, exclusive of disposal, was 52 dollars per acre in 1969. Based on the wholesale price index (U. S. Department of Commerce, Bureau of the Census 1974), the current 1974 cost for thinning cottonwoods would be about 76 dollars per acre assuming that all other factors remain the same. The economic feasibility of this treatment is difficult to quantify because the value of prevented flood damage and increased water yields are undetermined. A

monetary value for losses in fish and wildlife resources as a result of thinning treatments is also difficult to establish.

The Salt River Project Cooperative Cottonwood Thinning Program was terminated in 1969 because almost all of the available privately-owned riparian land in the Verde Valley had been treated (Warskow 1973). The remaining untreated riparian land is administered by the USDA Forest Service which did not accept an offer by the Salt River Project to cooperate in a cottonwood thinning program on USDA Forest Service land. Another reason for termination was adverse public sentiment concerning the effects of these projects on wildlife and aesthetics, primarily involving people living outside of the valley proposed for treatment.

ANTITRANSPIRANTS

The application of antitranspirant foliar sprays to reduce water use by plants is a potential treatment method for increasing water yield in riparian areas. Antitranspirants that close or narrow stomate apertures reduced transpiration rates of saltcedar plants in greenhouse and limited field studies (Brooks 1970). While most of the antitranspirants reduce growth rates to some extent, they were not found to be toxic to the saltcedar plants.

Justification for Water Yield Improvement

Tamarisk inhabits much of the floodplains in Arizona and the Southwest. Depending on environmental conditions and plant density, saltcedar stands transpire an estimated four to nine acre-feet of water per acre annually (Robinson 1965). Farming areas and municipalities in Arizona that are dependent on ground water for their water supply would benefit if these rates of water use were reduced. According to Brooks (1970), although tamarisk has little direct economic value, eradication has been opposed because: (1) wildlife habitat is destroyed, (2) significant ground water savings by vegetation removal have not been demonstrated, (3) aesthetic and recreational values of treated areas may be diminished, (4) effects on the ecosystem in general are

not well understood, and (5) rapid growth and reinvasion of tamarisk make eradication and continued suppression difficult to justify economically.

Combined with a limited channelization program, antitranspirants offer a possible alternative to eradication which has associated losses of wildlife habitat and greenery in the environment. However, field investigations of treatment effects on natural saltcedar thickets and the environment are needed to verify results of greenhouse studies and to determine the economic feasibility of this method. If antitranspirants are found to be effective in the field without causing harmful side effects, development of this management alternative may be mutually acceptable to water, recreation, and wildlife interests.

Hydrologic Response to Water Yield Improvement

Laboratory, greenhouse, and field experiments with saltcedar were conducted at The University of Arizona, Tucson, to determine the effectiveness of several antitranspirants, as well as the physiological response of treated plants.

Daily transpiration rates of young potted tamarisk plants, measured gravimetrically, were reduced 28 to 36 per cent for 20 days in the greenhouse, and for five days in the field after spray applications of 0.01 M 8-hydroxyquinoline sulfate (8-HQS), and a combination of 150 ppm monomethyl

(MDSA) and 150 ppm monoglyceryl (GDSA) esters of N-decenylsuccinic acid in Triton X-100 (0.5 per cent) solutions (Brooks 1970, Brooks and Thorud 1971). Growth was reduced for 10 to 20 days and net photosynthesis for less than one week following treatment. Whether or not growth reductions may have contributed to the decrease in transpiration rates was not determined. Foliage temperatures increased 2° to 3°C for three days following treatment.

Further antitranspirant studies were conducted by Cunningham (1971, 1972) to investigate the effects of repeated applications and artificial rainfall on treatment response and plant condition. Transpiration rates of plants receiving two treatments of 8-HQS and MDSA were 32 to 28 per cent less than control plants for a total of three to five weeks without damaging the plants. Simulated rainfall tests in the greenhouse suggested that rainfall may decrease the effectiveness of 8-HQS and MDSA, although results were inconclusive. As in previous studies, antitranspirant effectiveness was greater in the greenhouse than in the field.

The results of these experiments were projected to an operational scale by Cunningham, Brooks, and Thorud (1973). A conservative average evapotranspiration rate of 0.15 inches per day was assumed for natural saltcedar thickets and evaporation was considered to be a small component of evapotranspiration. The curves in Figure 3 are

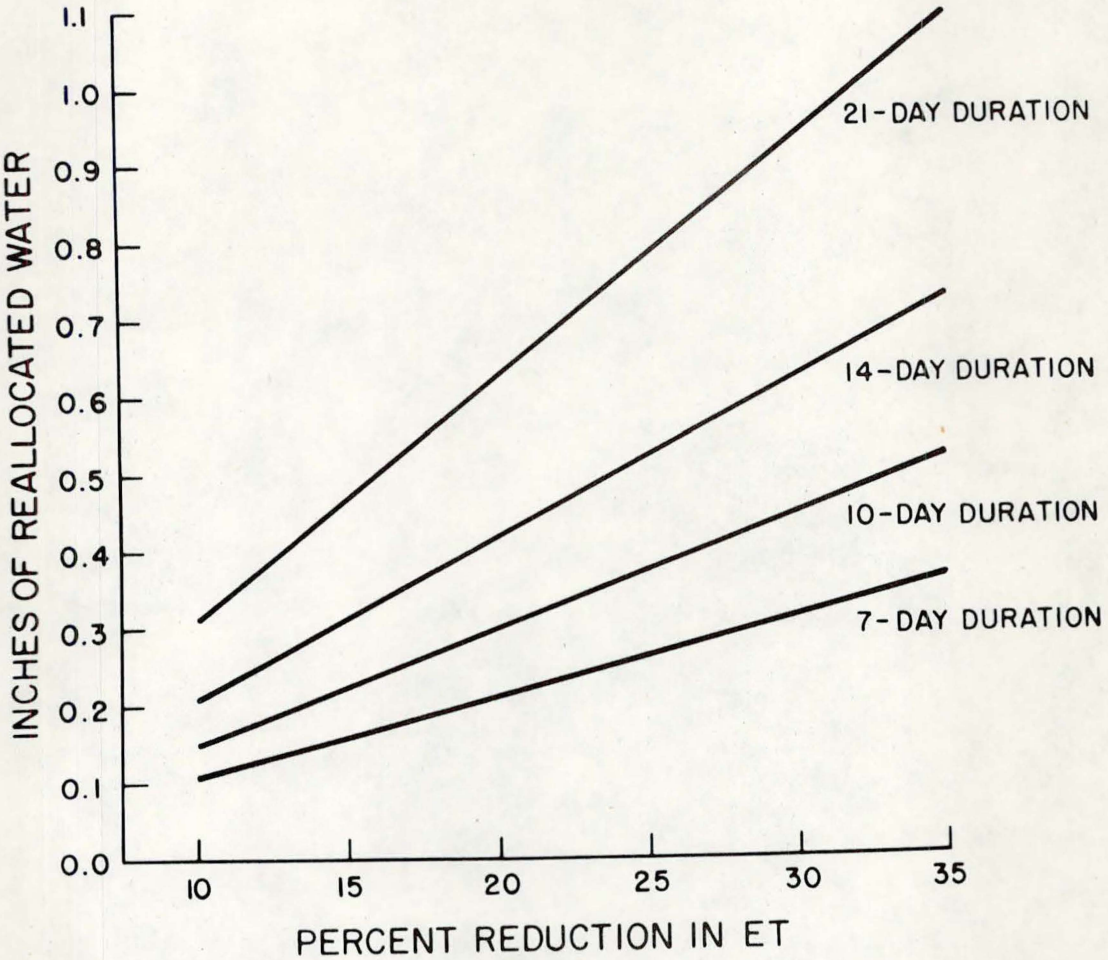

Figure 3. Estimated volume of reallocated water assuming an average saltcedar thicket evapotranspiration rate of 0.15 inches per day (Cunningham et al. 1973).

based on assumed values that encompass previous experimental results. In the example given, an estimated 88 acre-feet of water might be reallocated (refers to the disposition of water by means other than transpiration) if evapotranspiration were reduced by 25 per cent for 14 days following a single treatment of 2,000 acres of saltcedar. Assuming 13 similar treatments, an estimated 1,100 acre-feet of water could be saved over a six-month growing season. The most effective treatment considered (35 per cent reduction in transpiration for 21 days) when applied to a 2,000-acre thicket would result in an estimated 184 acre-feet of reallocated water following a single treatment.

Several factors may affect the validity of these computations as applied to actual field conditions. Extrapolating data obtained from young rapidly growing potted plants sprayed individually at close range to mature dense saltcedar thickets sprayed by aerial means in the field may lead to some large errors. The possibility of undesirable side-effects on wildlife, water quality, and other aspects of the environment should be evaluated before attempting an operational antitranspirant program. For example, 8-HQS apparently initiated chromatid-breaks in bean roots (Gebhart 1968a) and possibly caused gaps in chromosomes of human lymphocytes (Gebhart 1968b). No such reports have been encountered for the alkenylsuccinic acids. For these reasons, Cunningham et al. (1973) reported that field

investigations of treatment effects on natural saltcedar thickets and the environment are needed to further develop the concepts and verify the assumptions derived from greenhouse and limited pot studies in the field.

Influence on Other Natural Resources

Timber

The overstory vegetation is left undisturbed except for a small reduction in growth immediately after treatment.

Herbage

Because there is no eradication of riparian vegetation with the antitranspirant treatment method, there appears to be no possibility for grasses to become established in the treated area.

Wildlife and Fish

If the antitranspirant chemicals prove to have no side-effects on wildlife or the environment, this method would preserve the existing saltcedar habitat for whitewing dove and the songbird nesting habitat and retain refuge for small game animals. At the same time, water savings may be realized.

However, other factors should be considered. Effects of antitranspirants on phenological phenomena, if any, would be of importance to honey production. A reduction in water quality might affect the fisheries resource.

The effect on the ecosystem as a whole, especially food chains, would be of interest to plant and wildlife ecologists alike. Thus, comprehensive investigations should be carried out before antitranspirants are considered for large scale operations.

Recreation and Aesthetics

This method is the least destructive of vegetation and would, therefore, probably be most favored by recreation and aesthetic interests. However, impenetrable saltcedar thickets limit access to streamside areas and reduce the recreation value of riparian zones. For those who favor "green belts" this treatment method is ideal as the vegetation is left undisturbed except for possible limited clearing within the channel.

The application of antitranspirants to saltcedar or other associated vegetation has little impact on the plants themselves from a visual point of view. Possible leaf scorch may be ephemeral, a temporary effect lasting a few days to a week. However, if antitranspirant treatments were combined with the clearing of saltcedar from the river channel, there would be an associated visual impact. Clearing a clogged channel would expose the watercourse, resulting in a possible beneficial visual impact on landscape quality. The exposure of the watercourse would add a visual element of contrasting form, texture, and color.

Such treatment would preserve a greenbelt on one or both sides of the river channel and should add variety and contrast while decreasing possible monotony and homogeneity in the visual scene.

Economic Considerations

Direct Returns to the Land

This method of treatment may result in projected water savings as summarized in Figure 3. The most effective treatment considered suggested that a 35 per cent reduction in transpiration for 21 days would result in 1.1 area inches of salvaged water. However, these figures must be verified by further studies on an operational scale.

Direct Cost of Implementation

Costs for an aerial treatment program based on 1971 flying rates and chemical prices and ignoring any other costs associated with a treatment program were estimated to be $2.64 per acre (Cunningham et al. 1973). Using these data, the cost per acre-foot of reallocated water was calculated for several assumed magnitudes and durations of transpiration reduction following a single treatment of a hypothetical saltcedar thicket (Figure 4). The most effective treatment considered would result in 1.1 area inches of reallocated water at a cost of 30 dollars per acre-foot. These cost estimates, if valid for natural

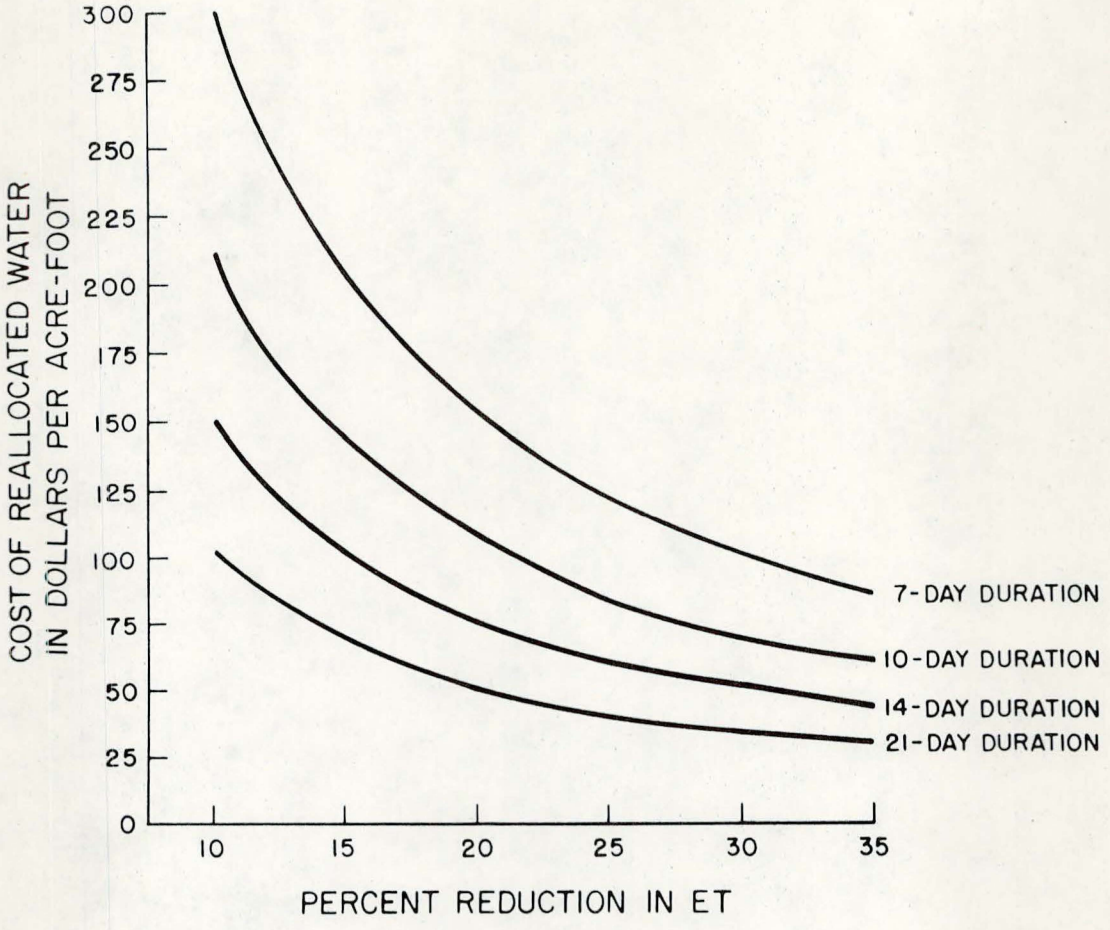

Figure 4. Estimated cost of reallocated water assuming an average saltcedar thicket evapotranspiration rate of 0.15 inches per day (Cunningham et al. 1973).

environments, seem to eliminate antitranspirant treatments as a feasible means for obtaining supplementary water from saltcedar thickets for use on relatively low value agricultural crops at this time, according to Cunningham et al. (1973). However, such costs, if supported and verified by further studies, may be acceptable if the salvaged water were utilized for municipal and industrial purposes, or for production of relatively high value crops.

Opportunity Costs

Opportunity costs associated with using antitranspirants include income foregone by not utilizing the treated floodplain for herbage production or cultivated crops.

Extent of Current Implementation

Antitranspirant treatments of saltcedar have not been applied on an operational scale in Arizona. However, the antitranspirant "mobileaf" was applied to a limited number of cottonwoods, willows, and saltcedar at the Lahonton Reservoir near Silver Springs, Nevada, in August, 1972. This work was conducted by the University of California, Davis, under a contract with the USDI Bureau of Reclamation. Relative transpiration rates were measured on treated and untreated leaves by electrical resistance and pressure chamber methods. A measurable reduction in transpiration was noted immediately from the six per cent

concentration but there was less reduction of transpiration from the ten per cent concentration (Bowser 1972). The effect on saltcedar was less pronounced with either concentration than on willow or cottonwood. A reevaluation of the trial approximately one month after application indicated a similar and continuing level of reduced transpiration rates from both the six and ten per cent concentrations. Further work is planned to evaluate transpiration rates over a long interval following antitranspirant application. Additional work is also planned to quantitatively determine water savings. The investigators believe that direct measurement of water content and indicated water loss by weighing potted plants can be used to estimate field effects with some confidence (Bowser 1972).

Potential for Future Implementation

Vegetative-Physiographic-Climatic Constraints

As was the case with previous treatments, the potential for water salvage with antitranspirants would be highest along relatively low elevation rivers where the combination of physical factors are such that riparian vegetation is transpiring large amount of ground water.

The effect of antitranspirants on fish, wildlife, and the environment have not been investigated under large scale field treatment conditions. If comprehensive

investigations demonstrate that antitranspirant chemicals have little or no side-effects on the environment, the method may be mutually acceptable to water, recreation, and wildlife interests.

Social-Economic-Institutional Constraints

The most effective antitranspirant treatment considered by Cunningham et al. (1973) indicated that it would cost 30 dollars to salvage one acre-foot of water. Limitations on the use of chemicals on the environment by government agencies such as the Environmental Protection Agency would be an institutional constraint for the use of antitranspirants on saltcedar communities for the purpose of salvaging water.

BIOLOGICAL CONTROL OF SALTCEDAR

Limiting the growth, spread, and water use of tamarisk by afflicting it with insect pests or plant pathogenic organisms is a potential method for improving water yields in Arizona. Past studies in the Southwest have included surveys of insects and plant pathogens associated with saltcedar. The most promising insects and plant pathogens were introduced to saltcedar plants in the field or greenhouse to determine their effectiveness as biological control agents. According to Gerling and Kugler (1972), who have conducted studies in Israel, the introduction and utilization of pests for the control of Tamarix could take place in the following three ways, depending upon the ultimate goal of the operation.

1. The complete destruction of Tamarix stands, for which several different insect species would be introduced into Tamarix communities.
2. A reduction in the number and vigor of the trees in existing stands. This would be a two phase operation, during which the entomophagous insects that are known to be controlled by natural enemies, would be introduced first without their enemies. Once the tree stands are affected to the desirable degree,

the second phase of introducing the natural enemies would take place.

3. The prevention of further spreading from the existing Tamarix populations. Although Tamarix is a perennial and has an abundance of seeds, it may be possible to prevent the production of new plants by utilizing insects which are specific flower, fruit, and seed destroyers.

Justification for Water Yield Improvement

The search for a biological control agent effective against saltcedar was initiated in the early 1950's. Investigators were interested in determining if saltcedar growth and spread could be materially limited with insect pests or plant pathogenic organisms (Hopkins and Carruth 1954). According to Liesner (1971), the high costs of saltcedar control by mechanical or chemical means prompted other methods of control to be sought which might be less expensive, one of which was biological control.

Hydrologic Response to Water Yield Improvement

There are no data available.

Influence on Other Natural Resources

The effects of using insects or plant pathogenic organisms to control saltcedar on timber, herbage, wildlife

and fish, and recreation and aesthetics are not known at this time.

Economic Consideration

There are no economic data available.

Extent of Current Implementation

Biological control of saltcedar has not been practiced on an operational scale in the Southwest. Past research has consisted primarily of appraisals of insects and plant pathogenic organisms found on or associated with tamarisk and subsequent testing of their suitability as biological control agents.

Surveys to provide information on the identity and activity of insects occurring on saltcedar were made in southern Arizona on or near the Gila, Salt, and Colorado Rivers at intervals between November, 1951, and May, 1953, by Hopkins and Carruth (1954). Fifty-eight different types of insects were identified. No evidences of insect injury were found which were sufficiently severe and widespread to support any assumption that saltcedar could be materially suppressed in Arizona by native insects alone.

A study of the phytophagous insect fauna of tamarisk was conducted in New Mexico during the 1968, 1969, and 1970 growing seasons by Leisner (1971). Sixty-five species of insects and one species of spider mite were collected and identified. A leafhopper, Opsius stactogalus Fieber, was

the only species collected in large numbers at all locations; however, it was not causing substantial damage to saltcedar. A host range study and review of the literature indicated that the leafhopper is host specific for the genus Tamarix.

Opsius stactogalus is either parasitized or preyed upon during all developmental stages. Eggs are parasitized by the parasitoid wasp Barypolynema saga; and, nymphs as well as adults are parasitized by the parasitoid wasp Gonatopus sp. During the weeks of July 17 and 24, 1970, Gonatopus sp. was recorded parasitizing 44 per cent and 30 per cent of all leafhoppers taken in population samples.

In order to determine the effects of various leafhopper populations on the growth rate of tamarisk, one- to three-year-old plants in the field were caged and stocked with different levels of leafhoppers weekly. Results indicated that if the leafhopper population was removed, growth was "greatly" accelerated; and if the population was increased growth rates decreased significantly. In addition, once a treated plant was affected, the effect was measurable after one complete growing season without further treatment. Liesner (1971) concluded that if Opsius stactogalus Fieber had not accompanied the importation of Tamarix spp., the annual spread of this phreatophyte would possibly be greater.

Effective biological control of saltcedar with native insect species does not appear to be feasible, and the importation of foreign species which might be more effective is an unpopular suggestion (Watts 1973). The Agricultural Research Service of the U.S. Department of Agriculture has a contract with Tel-Aviv University to evaluate enemies of noxious plants in Israel as potential agents for the biological control of weeds (Gerling and Kugler 1972). One of the plants being studied is saltcedar. About 50 species of Tamarix-feeding insects have been collected from Israel, India, Iran, and Turkey and are being evaluated by Gerling and Kugler (1972). The biology and ecology of some of these Tamarix-infesting insects, particularly those which may preclude seed formation, are being studied. This research may eventually result in suitable insects being imported to the United States for the control of saltcedar.

Scandone (1955) conducted a study to determine the feasibility of controlling saltcedar with plant pathogenic organisms. The project was divided into four phases over a period of three years. The first phase of the work was confined to the isolation of all microorganisms parasitic or saprophytic to saltcedar in Arizona. From saltcedar samples collected along the Gila River from Safford to Calva, Arizona, 20 pure cultures were eventually obtained, 18 of which belonged to various groups of fungi and two were

bacteria. In the second phase of the project each of the 20 isolates was inoculated into young saltcedar plants in the greenhouse. Three organisms appeared promising as pathogens on saltcedar: a bacterium tentatively named Bacillus tamaricis, a species of Helminthosporium, and a species of Alternaria. Crop plants of economic importance, cotton, alfalfa, castor bean, tomato, peanuts, and flax, were tested in the laboratory for their susceptibility to the three organisms. The tests were negative. In the third phase of work the three organisms were inoculated on saltcedar plants in field plots along the Gila River. The fourth phase of the study was designed to determine if the organisms sprayed on the saltcedar plants were present in tissues of the plants. Histological studies indicated that saltcedar in the areas studied was free from any natural occurring aggressive pathogens and that any large scale field inoculations would not eradicate or even seriously damage stands of saltcedar in and along river channels in the Southwest.

Potential for Future Implementation

No native insect species have adapted to tamarisk and Opsius stactagalus causes only limited chlorosis (Watts 1973). Scandone (1955) indicated that any large scale field inoculations of plant pathogens would not eradicate or even seriously damage stands of saltcedar in the Southwest. Studies in Israel and possible importation of foreign

insects may eventually help control the spread and water use of saltcedar plants.

SUMMARY AND CONCLUSIONS

Past studies and surveys indicate that Arizona has approximately 280,000 to 320,000 acres of riparian vegetation. However, pertinent information such as species composition, vegetation density, depth to ground water, ground water quality, and land ownership in riparian zones have not been accurately mapped except along the Lower Colorado River in 1963. The first four items and climatic conditions largely determine the amount of water utilized by riparian vegetation, and the last item, areas where water yield improvement practices may be implemented. In addition, riparian vegetative communities are subject to relatively rapid changes due to flooding, fluctuations in the ground water table, and the activity of man. Lack of accurate vegetation, ground water, and land ownership information makes accurate assessment of the potential for water yield improvement within the riparian vegetation zone difficult.

A continuous systematic survey and evaluation of riparian vegetation cover by aerial and satellite photography supplemented by ground truth would help remedy this problem. Specific riparian sites where environmental conditions are conducive to high evapotranspiration rates and where water yield improvement practices may be supplemented successfully could be determined with greater

accuracy than is presently available. In addition, a statewide survey of riparian vegetation would permit a more equitable allocation of riparian vegetation zones for water yield improvement, wildlife, recreation, and aesthetic purposes.

Vegetative, edaphic, geologic, hydrologic, and climatic factors combine to influence the amount of water lost by evapotranspiration in riparian zones. These factors include vegetative density, species composition, stage of growth, soil type and depth, soil and water salinity, depth to ground water, amount and seasonal distribution of precipitation, solar energy, humidity, wind speed, and length of growing season. Because these factors vary over time and space, all hydrologic studies conducted to determine actual water use by riparian vegetation under natural conditions have some degree of error and uncertainty associated with them. This is particularly true in instances where results from plot studies are extrapolated to natural areas. Analysis of hydrologic studies, however, may indicate identifiable trends in water use by riparian species. Saltcedar, arrowweed, cottonwood, and hydrophytes are the heaviest users of water (between four and eight feet of water annually). The intermediate water users (annual use between two and five feet) are seepwillow, mesquite, quailbrush, four-wing saltbush, and greasewood. The least amount of water (0.5 to three feet annually) is utilized by

grasses, sedges, and bare soil. Water yield improvement practices should only be instituted in areas where the riparian species consist predominately of the heaviest users of water.

Conversion Treatments

The removal of riparian vegetation on floodplains with depths to ground water of four to 20 feet, low soil and water salinity, and supporting dense, young, vigorous stands of higher water using species may yield water savings of up to 2.5 acre-feet per acre annually during the first year. However, some or all of this water may be used by replacement vegetation.

Depth to ground water is important in two respects with regard to evapotranspiration before and after vegetation conversion treatments. Some investigators have found that the amount of water transpired by riparian plants decreases as depth to water increases. Thus, the amount of water transpired in many riparian zones which support dense vegetation with a relatively deep water table (15 to 20 feet) may be overestimated. Little water would be salvaged when these areas are cleared. After riparian vegetation is removed, the ground water depth determines to a large extent the types of plant species which can be utilized as replacement cover. If depth to water is greater than eight or ten feet, grass species probably will not

become established and if the water table is less than four or five feet deep, comparatively large evaporation losses may occur regardless of plant cover characteristics. It appears that depth to ground water may place a restriction on those areas which are suitable for successful conversion treatments and should receive more consideration in the future.

Several additional constraints exist which tend to reduce opportunities for converting a large portion of the estimated 280,000 to 320,000 acres of riparian vegetation in Arizona. Possible detrimental effects caused by removal of riparian vegetation in conversion treatments include loss of wildlife habitat, chemical herbicide contamination, lowered aesthetic quality, and increased soil erosion during the initial stages of conversion treatments. The exact proportion and location of riparian land in public and private ownership is not summarized for many sections of Arizona. If conversion projects are undertaken in the future, those areas which are privately owned or in wildlife refuges may be unavailable for treatment.

Economic data are unavailable to complete benefit/cost studies for conversion treatments. While there is substantial information on costs of mechanical and chemical treatments, there are little or no economic data on the other resource outputs or losses of such treatments. In addition, no acceptable methods have been developed to

quantify effects of such treatments on wildlife, recreation, and aesthetics. The lack of explicit information in published literature on conversion programs makes it difficult to determine if economies of scale are present.

Annual equivalent cost figures indicate that if two acre-feet of water per acre can be obtained by conversion of 5,000 acres, the cost to produce it based on dollar values for 1974 will range between $2.30 and $15.60 an acre-foot annually for 50 years. These relatively low costs for the production of water warrant further investigation of conversion projects. On the other hand, such figures do not include losses of fish and wildlife, recreation potential, and aesthetic quality nor possible benefits from increased herbage production or reduced flood hazards.

In higher elevation riparian zones, the USDA Forest Service and the USDI Geological Survey have conducted research on riparian vegetation clearing and conversion treatments which indicate that significant water may be salvaged. However, the USDA Forest Service considers the 5,000 acres of riparian vegetation on USDA Forest Service land as an insignificant amount for treatment to increase water yields and apparently has no present plans to conduct riparian conversion programs on an operational scale.

Pressure by the Arizona Game and Fish Department, various environmental groups, and the general public to

preserve riparian zones for fish and wildlife habitat, recreation, and aesthetic values, coupled with the required environmental impact statements has caused most planned treatment programs by federal agencies in Arizona to be suspended or delayed. Environmental groups and the Arizona Game and Fish Department contend that water savings, if any, are unknown, and the economics of such treatments are not known.

In view of the several constraints discussed above and the trend toward multipurpose management of floodplains rather than singlepurpose management a program of limited selective clearing in Arizona seems to be indicated. Conversion projects should be undertaken only in instances where the benefits of water salvage, increased herbage production, and flood control outweigh the detrimental effects on wildlife, recreation, and aesthetics. It appears that the detrimental effects on wildlife, recreation, and aesthetics and other social and ethical factors can not readily or appropriately be valued by the market nor be realistically weighed in the calculation of benefits and costs. Thus they should be assessed and evaluated in plain textual terms by decision makers. Public and private landowners who benefit from an increase in water supplies should finance the cost of those management practices which are attributable to the water supply objective. Means of capturing and utilizing the additional supply of water from

onversion treatments have been neglected. The means of revegetating cleared riparian lands and determining the value of forage produced have also not been thoroughly investigated. These two areas of neglect should be investigated further in order to justify conversion treatments as a suitable means of increasing the water supply in Arizona. Follow up studies of current conversion projects should be conducted in depth to determine quantitatively the rates at which revegetation takes place, declines in water salvage as revegetation occurs, changes in water table depth after clearing, amount and value of increased herbage production, and long term effects on plant and animal ecology.

Channelization

Extensive portions of the Colorado River from Davis Dam to the Mexican border were channelized by the USDI Bureau of Reclamation. Portions of the Gila and Salt Rivers have been authorized for channel improvements by the U.S. Army Corps of Engineers. However, these projects are delayed pending the outcome of litigation initiated by environmental groups, or because environmental impact statements have not been approved.

The physical factors which influence the amount of water transpired by riparian vegetation discussed above are also important when considering channelization treatments for water salvage. Only riparian zones where plant and

environmental conditions are optimal for high evapotranspiration rates should be considered for water salvage by the channelization method. Depth to ground water on the floodplain before and after treatment is a key factor in channelization projects designed to reduce water use by riparian vegetation. Channelization would be of little use in areas where the water table is relatively deep (20 to 30 feet) and supporting a sparse riparian growth. In areas where the water table is 10 or 15 feet deep prior to channelization, results of further lowering the water table on evapotranspiration are imperfectly known. While many tank studies have shown water use by riparian species to decrease as depth to the water table increased, the Bernardo tank studies in New Mexico did not. The rate at which the water table is lowered by channelization may be important. The faster the rate, the less likely the roots of riparian species will be able to grow to the vicinity of the water table. Timing of channelization projects is one factor which has not been discussed in the literature. Because riparian vegetation is deciduous and becomes dormant, winter may be an ideal time to lower the water table. Then, in the spring months, high plant growth and transpiration rates, root systems not in contact with the water table, and low precipitation would possibly combine to create a large stress on the plants which may subsequently expire.

Good locations for channelization projects appear to be areas which require both additional water and protection from flooding. However, vegetative and hydrologic conditions at the terminus of channelization projects should also be considered. Where channelization ends at the head of a reservoir there may be no difficulty, but in other cases, problems of riparian vegetation water use and flooding may only be translated downstream.

Channelization programs in Arizona designed to reduce water use by riparian vegetation and flood hazards have several constraints. The impact of channelization on wildlife may not be as severe as it is with mechanical and chemical conversion treatments because not as much vegetation is removed. However, detrimental effects to both fish and wildlife occur when marsh areas and sloughs dry up because of lowered water tables, or are filled in with dredge spoil. These effects can be ameliorated to some extent, as was done along the Colorado River by installing inlet and outlet structures to provide fresh water to backwater areas which became isolated by the channelization process. Channelization projects which include levees or cement lined channels may act as barriers to wildlife, and instances of drowned deer and mountain goats have been reported in the Yuma area.

Channelization destroys the natural character of a river. Eliminated meanders, concrete-lined channels,

riprapping on banks, and dredge spoil deposits along edges of channels create an unnatural landscape which may be aesthetically displeasing.

Economic data for three U.S. Army Corps of Engineers channelization projects proposed for Arizona indicate that such projects are expensive and may be more justified for their flood protection benefits than for water salvage. It appears doubtful at the present that these projects will be constructed because of low benefit/cost ratios, opposition by environmental groups, or because ground water pumping for agriculture has already lowered the water table beyond the rooting zone of phreatophytes.

The potential for channelization projects in Arizona is low at the present. Channelization may be justified in certain specific instances such as in opening up clogged channels at the head of reservoirs or protecting structures and functions already existing on the floodplain. However, channelization should only be used when all other possibilities have been ruled out by pre-project planning.

Cottonwood Thinning

Cottonwood thinning is primarily designed to reduce evapotranspiration and flood hazards. Thinning prevents buildup of debris dams which divert water out of the channel area during peak flows. Other benefits include increased

herbage production and possibly a more aesthetically pleasing area for recreation.

Extensive thinning of cottonwoods in Arizona has been conducted only in the Verde Valley where 1,029 acres were treated on Oak Creek and the Verde River. These treatments were accomplished by contractual agreements between the Salt River Project and private landowners.

Measurements of any increased water yields from the thinning treatment were not obtained. However, based on research results of the USDI Geological Survey-Cottonwood Wash Study estimates of water yield increases of two acre-feet per acre annually have been made.

Higher elevation riparian communities along perennial streams in Arizona provide habitat for many species of wildlife and indirectly benefit fish habitat. Both fisheries investigations and studies of bird nesting densities suggest that fish and bird populations were reduced as a result of the cottonwood thinning program in the Verde Valley. In addition, no regeneration of cottonwood has occurred because of cattle grazing in the thinned treatment areas.

The cost for thinning cottonwoods on the Verde River exclusive of debris and slash disposal was 52 dollars per acre in 1969. Based on the wholesale price index (U.S. Department of Commerce, Bureau of the Census, 1974), the current cost (1974) for thinning cottonwoods would be 76

dollars per acre. The value of prevented flood damage, amount of increased water yield, and increased herbage are unknown, which makes an economic evaluation of thinning treatments difficult. In addition, the value of fish and wildlife lost as a result of the thinning treatment were not considered.

The Salt River Project's Cooperative Cottonwood Thinning Program was terminated in 1969 because almost all available privately owned riparian land in the Verde VAlley had been treated and because of adverse public opinion concerning the effects of the project on wildlife and aesthetic qualities, primarily from people living outside of the Verde Valley. However, limited thinning of cottonwoods in some areas may be beneficial where property values warrant its use such as in preventing bridges from washing out or protecting structures on the floodplain.

Antitranspirants

The application of antitranpsirant foliar sprays to reduce plant water use is a potential treatment method for increasing water yield in riparian zones. Antitranspirants that close or narrow stomate apertures were effective in reducing transpiration rates of saltcedar plants in greenhouse and limited field studies. Daily transpiration rates of plants, measured gravimetrically, have been reduced up to 38 per cent for a total of three to five weeks after spray

applications of 8-hydroxyquinoline sulfate and a monomethyl ester of N-deceylsuccinic acid.

The results of these experiments were extrapolated to an operational scale by Cunningham et al. (1973). The cost per acre-foot of salvaged water was calculated for several assumed magnitudes and durations of transpiration reduction following a single treatment of a hypothetical saltcedar thicket. The most effective treatment considered would result in an estimated 1.1 area inches of salvaged water at a cost of 30 dollars per acre-foot based on 1971 flying rates and chemical costs. Several factors may affect the validity of these computations. Extrapolating data obtained from young rapidly growing potted plants sprayed individually at close range to mature dense saltcedar thickets sprayed by aerial means in natural field situations may lead to some large errors. Rainfall may decrease the effectiveness of antitranspirants, although results of simulated rainfall tests in the greenhouse were inconclusive. The possibility for harmful side-effects of antitranspirants on wildlife, water quality, and other aspects of the environment need to be evaluated before attempting an operational antitranspirant program.

Research into the feasibility of obtaining supplementary water from saltcedar thickets and other riparian species through the application of antitranspirants should be continued and expanded. Antitranspirants offer a

possible alternative to more extensive eradiation with its resultant loss of wildlife habitat and greenery in the environment. Although the costs of antitranspirant treatment may be greater in comparison to other water yield improvement methods, the increased cost may be justified because wildlife, recreation, and aesthetic values of the riparian zone would be left undisturbed. In addition antitranspirants provide greater flexibility in their use compared to other methods. They could be applied at times when transpiration rates are highest, in areas where water is needed most, or not applied at all during wet years when there is no need for increased water yields. Another benefit of antitranspirants in comparison to eradication methods is that the riparian canopy remains intact, thus shading the soil surface and reducing possible soil evaporation losses. If antitranspirants are proven to be effective and safe, the development of this managment alternative may be mutually acceptable to water, recreation, and wildlife interests.

Biological Control

Limiting the growth, spread, and water use of tamarisk by afflicting it with insect pests or plant pathogenic organisms is a potential method for improving water yields in Arizona. Past studies in the Southwest have included surveys of insects and plant pathogens associated

with saltcedar. The most promising insects and pathogens were introduced on saltcedar plants in the field or greenhouse to determine their effectiveness as biological control agents.

Results of these studies indicate that no native insects or plant pathogens tested had any material effect on saltcedar. Thus, the potential for water salvage using biological control appears to be low. However, foreign species may be found which can be safely imported to control saltcedar.

APPENDIX A

INDIVIDUALS AND ORGANIZATIONS CONTACTED

Jerome S. Horton Charles J. Campbell	USDA Forest Service Hydrology Laboratory, Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona
Richard C. Culler Durl E. Burkham Raymond M. Turner	USDI Geological Survey Tucson, Arizona
Curtis Bowser Elwyn Krous Sten Freeland Robert Sparks Eldon Johns	USDI Bureau of Reclamation Region 3 Boulder City, Nevada
Oliver H. Lillard David E. Creighton, Jr.	USDI Bureau of Reclamation Arizona Projects Office Phoenis, Arizona
R. E. Schembera	USDI Bureau of Reclamation Albuquerque Development Office Albuquerque, New Mexico
H. W. Worthington, Major	U.S. Army Corps of Engineers Phoenix Resident Office Phoenix, Arizona
Mr. Ramsbocker William Carter Virgil Hart	USDI Bureau of Land Management Phoenix, Arizona
Dannie E. LeCrone	Bureau of Indian Affairs Phoenix, Arizona
Bud Bristow	Arizona Game and Fish Department, Phoenix, Arizona
Don Welch	USDI Bureau of Sport Fisheries and Wildlife, Division of River Basin Studies, Phoenix, Arizona

Joe Arnold Joe Baldwin Bob Gale Howard Broderick	USDA Forest Service Phoenix, Arizona
William Warskow	Salt River Project Phoenix, Arizona
Joe Melling	State Land Department Phoenix, Arizona
John Tromble	Agricultural Research Service Southwest Watershed Research Center, Tucson, Arizona
William G. McGinnies Edward F. Haase	Office of Arid Land Studies Tucson, Arizona
Herbert M. Hull Howard L. Morton	Agricultural Experiment Station The University of Arizona Tucson, Arizona
J. G. Watts	Department of Botany and Entomology, New Mexico State University, Las Cruces, New Mexico
David Davenport	Department of Water Science and Engineering, University of California, Davis, California
R. Roy Johnson	Prescott College Prescott, Arizona
T. E. A. Van Hylckama	USDI Geological Survey Lubbock, Texas
George Proctor Dale Jones Bob Williamson Bill Currier Ralph Solether Bill Russell Ken Bowman Eric Sievert Lloyd Barnet Ivan Fish Bill Larsen Tom Roderer	USDA Forest Service, Region 3 Albuquerque, New Mexico

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